THE EFFECTS OF HYDROLOGY AND NUTRIENT INPUTS AT SOUTH MILTON LEY ON THE ECOLOGY OF THE COMMON REED *PHRAGMITES AUSTRALIS* (Cav. Trin. ex Steudal)

by

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We need the tonic of wilderness - to wade sometimes in the marshes where the bittern and the meadow hen lurk, and hear the booming of the snipe; to smell the whispering sedge where only some wild and more solitary fowl builds her nest, and the mink crawls with its belly close to the ground. At the same time that we are earnest to explore and learn all things, we require that all things be mysterious and unexplorable, that land and sea be infinitely wild, unsurveyed and unfathomed by us, because unfathomable. We can never have enough of nature.

Henry David Thoreau

1817-1862

The Effects of Hydrology and Nutrient Inputs at South Milton Ley on the Ecology of the Common Reed *Phragmites australis* (Cav. Trin. ex Steudal)

Paula Angèlé Powell

ABSTRACT

South Milton Ley is a small coastal wetland in Southern England. A sand-bar forms periodically at its seaward end and separates fresh water from the sea. The common reed *Phragmites australis* dominates the wetland and when a sand bar is present a shallow freshwater lake forms.

Monthly water budgets were prepared for the years 1994, 1995 and 1996 and intermittent flooding of the Ley was also monitored. This information was used to calculate a range of residence times (between one hour and eleven days) and the characteristics of various flow regimes when the sand-bar, which dams the Ley, is open or closed.

Reed growth and the lake's ecology are potentially influenced by effluent from a sewage treatment works (STW) that discharges into the wetland. Water chemistry and hydrology of the wetland have been studied alongside experiments to investigate any effects of nutrient enrichment from the STW on reed growth.

Inflowing and outflowing waters were analysed in order to determine concentrations of total oxidised nitrogen (TON), total dissolved nitrogen (TDN), soluble reactive phosphorus (SRP), total dissolved phosphorus (TDP) and potassium (K). Over the study period the annual load of SRP to the Ley increased from 3.65 g m^{-2} a^{-1} in 1992 to 8.1 g m^{-2} a^{-1} in 1996. TON load rose from 69.35 g m^{-2} a^{-1} in 1992 to 104.8 g m^{-2} a^{-1} in 1996. K fell from 97.3 g m^{-2} a^{-1} in 1994 to 96.4 g m^{-2} a^{-1} in 1996.

The STW uses a Reedbed Treatment System (RBTS) to 'polish' its final effluent. The efficiency of the RBTS was studied and during 1996 the efficiency rate for TON was 20.9% and for SRP was 9.3%.

Measurements of height, diameter, numbers of internodes, density and biomass of reeds collected from South Milton Ley were undertaken during August 1994 and 1995. Results of analyses for 1994 indicate that reeds were thinner and possessed fewer seedheads than those of 1995 but that density was greater. Reed fieldwork during 1994 found that height, diameter, numbers of internodes, biomass and number of seedheads were greater below the STW than above. During 1995 only seedhead production was greater below the outlet. The wettest area of the Ley contained reeds with greatest height and diameter. The driest area produced a higher density of reed growth. Laboratory experiments suggested that low N:K ratios and high P:K produced taller plants.

Data from reed fieldwork together with results from hydrology and water chemistry studies were used in a statistical analysis in order to determine which, if any of these factors caused changes in reed growth. A conclusive link between water chemistry, hydrology and plant variables was not found. Correlation analysis for 1994 indicated that high concentrations of SRP and TON could produce thin reeds with low biomass. Analysis for 1995 suggested that elevated K values could produce a high density of short reeds. Water depth was found to have a significant effect ($P < 0.001$) on diameter.

The key factors for reed decline (high water levels from spring to winter which can inhibit reed regeneration and increase residence times, increasing nutrient loads and changes in the ratio of N:P:K which could alter reed growth) are all present.

At its present loading the Ley is nutrient rich and does not appear to be buffering wetland waters.

After data analysis and fieldwork was completed a bloom of *Oscillatoria* sp.occurred at the seaward end of the Ley during August 1999. This, the first know occurrence of a bloom may be an indication that changes in the ecosystem of South Milton Ley are occurring. For the future, a programme of nutrient reduction, hydrological management and growing knowledge of wetland processes may prevent adverse changes.

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AUTHOR'S DECLARATION

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CHAPTER ONE

Introduction

This study is concerned with the effects of nutrient enrichment on *Phragmites australis* (Cav. Trin. ex Steudal). Fieldwork has been undertaken at South Milton Ley, a Site of Special Scientific Interest in South Devon. This is a freshwater wetland which receives effluent from a sewage treatment works and diffuse inputs of nutrients from surrounding farmland.

In 1991, South West Water applied for consent to discharge effluent into South Milton Ley from an extended sewage treatment works at South Milton. The new works incorporated an artificial reedbed system which was to act as a 'tertiary system' for the increased effluent flow. English Nature expressed concern at the consent levels set by the National Rivers Authority and the long-term effects of raised nutrient levels on the Ley.

The application was referred under the Water Resources Act 1990 to the Secretary of State for the Environment but the consent to discharge was not called in. English Nature continued to be concerned about the potential impact of raised nutrient loadings to the Ley particularly as no long-term studies of the system or of the efficiency of artificial reedbed systems had been carried out.

This research aims to test whether the waste water discharge from South Milton sewage treatment works into South Milton Ley is, by increasing existing nutrient loads, causing detrimental changes to plant biomass, physiology and water quality.

In order to assess the performance of *P. australis* physical variables of height, diameter, and biomass were measured in various zones of the Ley. These measurements have been correlated with surface, effluent and soil water analysis for nitrogen, phosphorus and potassium. Experimental laboratory work was also carried out in order to determine the effects of N:P:K ratios on the growth and structure of *P. australis*. A hydrological study was undertaken in order to monitor fluctuations of water depth and streamflow rates and their effects on the nutrient balance of the Ley and also reed growth.

CHAPTER TWO

Wetlands - Their Roles

2.1 Part One - Hydrology

Wetlands are dynamic ecosystems with fluctuating boundaries. They are defined by **Cowardin** ***et al.*** **1979 pp. 393**, as

> "land transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is covered by shallow water".

Within this broad definition wetlands can be subdivided in the following ways according to systems function rather than by morphological, taxonomic or habitat criteria (**Howard-Williams 1985**):

a) Permanently inundated or periodically inundated wetlands. The seasonal drying up of a wetland will influence the way the system functions. As the aquatic component disappears, soil microbial processes become terrestrial and aquatic vegetation is available to consumers from adjacent terrestrial areas;

b) Freshwater or brackish wetlands. The latter if along the coast, are characterised by two directions of flow, one of which is often more saline than the other;

c) Periodically frozen or continuously non-frozen wetlands. Nutrient cycling in the former is intermittent and affected by freezing or physical stresses;

d) Rooted or floating wetlands. Rooted wetlands are the common type in temperate regions. The major vegetation is rooted in the sediment and plays an important part in nutrient cycling. Examples would be the *Phragmites* reed swamps of Europe and the *Typha* and *Scirpus* marshes of North America.

2.1.1 Hydrogeological Classification of Wetlands

Cowardin ***et al.*** **(1976)** have described wetland systems using hydrogeological classifications.

Riverine systems exist where the principal source of inflow is surface water in stream channels. Wetlands that fringe such rivers may be areas where seepage of river water into groundwater takes place. Similar wetlands may be created by discharging wastewater down a channel, some of which will infiltrate into the ground and recharge the water table. Whereas nutrient fluxes in riverine systems are seasonal and high, those of fringe wetlands exhibit continual lateral exchanges through bi-directional flushing since they frequently interact with large water bodies (for example in coastal environments). **Brinson (1988)** suggests that fringe wetlands are of more importance as habitats for wildlife than for water quality and that therefore should be protected from high levels of nutrient input rather than used as assimilators.

In a lacustrine wetland, hydrogeology is a function of the morphology of the lake basin. Stands of emergent vegetation frequently occur along the margins of lakes. The overall water balance of the body regulates water levels in this type of wetland. Palustrine systems are non-tidal wetlands which are not confined by channels and are not marginal to lakes. They are hydraulically isolated from open surface water so that ready exchange of water does not take place.

Wetlands are therefore complex and varied systems. Many do not fall wholly into the classifications which have been described but possess a combination of characteristics. The combination can depend on factors which operate at different times of the year. For example at South Milton Ley one type of system is embedded within another. These may behave as riverine or fringe and lacustrine depending on the action of the storm beach and sand bar.

2.1.2 The Role of Hydrology in Freshwater Wetlands

Gosselink and Turner (1978) describe the hydrological regime as the controller of wetland ecosystems and suggest that the source, the renewal rate and the timing of the water influx directly influence or modify such systems. Source determines the chemical composition of the water, whereas the velocity affects turbulence and the ability to carry suspended particulate matter. Renewal rate describes the frequency of replacement of the water. The timing (frequency of seasonal or daily inundation) and its regularity influence the potential for succession and maturation (**Margalef 1975**).

Hydrological change may be the most important indicator of wetland alteration (**Brinson 1988**). Since many relationships are present, including water velocity versus erosive capability, water level versus water flow and water table depth versus sediment aeration, significant impacts on wetlands should be examined as being potentially cumulative (**Hemmond and Benoit 1988**).

Hydrologic conditions can affect the removal of wastewater nitrogen and phosphorus. **Nichols (1983)** reported that as the loading rate of effluent increased there was a rapid decline in the efficiency of nitrogen and phosphorus removal. Thus at high hydraulic loadings the retention period is reduced and less time is available for removal reactions to occur. Wetland morphology influences nitrogen and phosphorus by increasing or decreasing the depth of water. The chance for transformations between wastewater and soil is reduced as depth increases. However the retention time of a deep wetland will be longer than that of a shallow system given the same hydraulic loading (**Nichols 1983**).

2.2 Part Two - Nutrient Enrichment Pathways

Most wetlands which possess surface hydrological inputs and outputs are open systems, receiving a constant subsidy of water and nutrients from external sources (**Klopatek 1975**). Phosphorus is the key controlling nutrient for aquatic plant growth whereas nitrogen is ranked as second, (**Lee, Rast and Jones 1978; Vollenweider 1985**). However the conditions which cause wetlands to be net importers or exporters of such nutrients are still not fully understood (**Good, Whigham and Simpson, 1978; Hasler 1975; Burton and Liss 1976**).

Lakeshore and riverine plants extract nutrients from deep sediments and return them to the environment by three processes: leaching of above-ground tissues into surrounding water, translocation to below-ground structures where they are either stored or released through decomposition and release via decomposition of litter (**Whigham *et al.* 1978**). In high-energy tidal or flowing freshwater conditions litter may be swept away but in low energy lake-shore systems it decomposes and accumulates as peat. The 'leaking' of nutrients in litterfall conserves nutrients within the ecosystem (**Etherington 1983**).

In flowing-water systems, import and export of some elements vary seasonally. Thus analysis of wetland discharges shows that plant uptake reduces concentrations of elements such as phosphorus, calcium and magnesium during spring and early summer but that in late summer the situation is reversed because a pulse of nutrient is released either by leaching of litter or by mineralisation (**Etherington 1983**). By contrast nitrogen is permanently lost from the system by denitrification which requires anaerobic conditions and a supply of organic carbon and is affected by temperature and pH (**Nichols 1983**). Nitrogen is also immobilised from wetland waters by sedimentation and accumulation by plants.

The capacity of wetland soils to retain or release nutrients such as phosphorus depends on their mineral content. Phosphate is chemically adsorbed by hydrous iron, aluminium oxides and clay minerals, physically adsorbed by soils and removed from solution by precipitation (**Nichols 1983**). If phosphorus is continually added to the system (for example in treated waste water), the absorbance capacity of wetland soils will decline as they become saturated. Adsorption-precipitation by soils is not a limitless sink and is partially reversible. This can occur by a reduction in phosphate concentration in the solution in contact with the soil, by plant uptake or by flushing or dilution with low phosphate water which will release the element into solution (**Nichols 1983**).

Gehrels and Mulamoottil (1990) in a study of hydrological processes in a southern Ontario wetland found that whilst it was retaining large amounts of phosphorous, internal processes may have been converting sediment bound phosphate to plant available orthophosphate. They suggest that it may be more appropriate to depict wetlands as transformers of nutrients rather than nutrient sinks. The assumed function of wetlands as minimising eutrophication in receiving water bodies is thus questionable.

2.2.1 Nutrient Enrichment

Edmondson (1981) describes eutrophication as an increase in the rate of income of nutrients. The symptomatic effects of increased concentrations of plant nutrients such as nitrogen and phosphorus are manifested by enhanced production of planktonic and attached algae and other aquatic macrophytes and by general deterioration of water quality (**Kolenbrander 1972**), with repercussions for the overall metabolism of the wetland (**Vollenweider, 1968**).

Cultural eutrophication is caused by an increase in nutrients, mainly nitrogen and phosphorus, related to human activity (**Deevey 1984**). The major external human inputs may enter a wetland via point or nonpoint sources. A nonpoint load is diffuse, so localised effects of high concentrations are unlikely. An example is agricultural runoff which contributes 50-60% of all nitrogen, and 20% or less of phosphorus in surface waters in England (**Arden-Clarke, 1988**). Effluent from industrial or domestic point sources such as sewage treatment works may create localised regions of high concentrations near their discharges and cause diffuse effects far from the source. Domestic sewage is responsible for approximately 80% of the phosphorus entering freshwaters in the UK (**Holden 1976**).

2.2.2 Domestic Wastewater

Nitrogen compounds occur in sewage effluent as ammonia, nitrate, nitrite, soluble organic constituents and suspended or organic material. The reduction of ammonia toxicity in receiving waters is achieved in secondary, biological treatment by oxidation of ammonia to nitrite and nitrate (nitrification), (**Barnes *et al.* 1981**). These components can be removed during tertiary treatment by reduction to nitrogen gas (denitrification).

Phosphorus is present in raw sewage as orthophosphate and as biological compounds such as phospholipids, nucleic acids and phosphorylated proteins. Secondary sewage treatment removes 20-30% of soluble phosphate (**O'Neill 1985**), of which a high proportion comes from detergents. Up to 90% can be removed by tertiary treatment using activated sludge or 'phostrip' (**Winkler 1981**). The amount of nitrogen and phosphorus present in the effluent discharged from a sewage treatment plant depends on the quantity of flow including storm overflow, the concentration of the constituents in the incoming wastewater and the type of treatment (**Harper 1992**).

The removal of wastewater N and P by wetlands is most efficient at low loading rates but the removal efficiency falls off rapidly as loadings increase (**Nichols 1983**).

2.2.3 Nutrient Removal From Domestic Wastewater by Artificial Wetlands

The use of constructed wetlands to treat domestic wastewater was pioneered by Dr Kathe Seidel during the 1950s (**Howard-Williams 1985**). Since then the use of these systems has grown and the technology has been further developed.

Reed bed treatment systems (RBTS) depend on the flow of sewage through a bed of either soil or gravel in which common reeds, *Phragmites australis* are growing (**Cooper and Hobson 1988**). The principle of the RBTS is to create horizontal flow of effluent within the bed in order to enable it to receive treatment in the rhizospheres (root zone) of *Phragmites* (**Findlater *et al.* 1990**). This is best achieved if the rhizomes of reeds grow both vertically and horizontally, which opens up the soil to provide a 'hydraulic pathway' for the flow. The wastewater is then treated by heterotrophic and autotrophic bacteria which colonise the plant roots and substrate. Oxygen which is needed for aerobic bacterial activity in the root zone is passed through the leaves and stems to the hollow rhizomes (**Cooper and Hobson 1988**).

The size of most UK RBTS is 3-5 m^2 per person and the planting density of *Phragmites australis* is 2-4 stems m^{-2}. Gravel based systems are favoured because of their high hydraulic conductivity (**Mann 1990**). According to **Arthur (1986)** for any significant removal of phosphorus to occur, the bed medium should be high in iron or preferably aluminium content (as found in reed beds grown in soil).

Kickuth (1985) has stated that the hydraulic conductivity of a gravel bed would take 3-5 years to develop fully and that during wet weather some excess flow would pass over the bed and will need to receive treatment at the surface layer. **Cooper (1990)** in a study of 500 RBTS in Europe found that excessive surface flow exceeding permeability of the substrate was the main cause of low nutrient removal. His findings show that removal of total ammonia-nitrogen was 20-30% and total phosphate-phosphorus 30-40%.

2.2.4 Efficiency of Reed-bed Treatment Systems

Spangler *et al.* (1978) found that there is a positive relationship between the retention time of the effluent throughflow and phosphorus and nitrogen removal in an artificial wetland. Their study showed a reduction in total phosphorus which varied between 5% and 25%, whilst 'removal' of dissolved inorganic nitrogen (90% of which was NO_3-N) was highly variable ranging from an increase of 47% to a reduction of 60%. Seasonable variability has also been found with greater efficiency during the summer and spring than in winter (**Christian 1990**).

Findlater ***et al.*** **(1990)** found from studies of the RBTS in operation in the UK, that as the roots of the plants in the soil and gravel media became established efficiency improved, but that ammoniacal-nitrogen and phosphorus removal remained poor. Effluent loading rate is also important to the efficiency of RBTS. **Nichols (1983)** reported that nutrient removal is generally high at low loading rates and low at high loading rates. He has estimated that for every 60 people 1 ha of wetland is needed for 50% nitrogen and phosphorus removal and approximately 1 ha for every 20 people for 75% removal.

The advantages of the constructed reedbeds including those of low capital and maintenance cost and appropriate technology for small communities have been widely documented **Nichols (1983), Cooper and Hobson (1988), Findlater** ***et al.*** **(1990). Wolstenholme and Bayes (1990) and Howard-Williams (1985)** conclude from their studies that there is doubt as to the suitability of RBTS for achieving sustained nutrient removal. They recommend further studies aimed at improving the efficiency of the nutrient removal processes and loading application rates.

2.2.5 Consents to Discharge Sewage Effluent

Under the Environment Act 1995 the Environment Agency (EA) took over the role of the National Rivers Authority. As has been previously the case discharges of sewage effluent to water are regulated through a system of consents. Polluting controlled waters is an offence as is discharging effluent in breach of a prohibition. The EA holds responsibility to set consents for all sewage treatment plants which discharge into controlled waters (**Water Resources Act 1991**).

Three types of consents may be granted:

a) numerical: whereby special limits of flow and concentrations of constituents are set. Compliance is maintained by regular sampling;

b) descriptive;

c) non-numerical.

All numerical consents for discharge of relevant determinands should include absolute or maximum limits. Mass-balance modelling techniques are used in order to determine relevant water quality standards for receiving waters (**NRA, 1990**). From this, percentile concentrations, under which certain constituents should be kept below a determined level for a percentage of the time, are then established.

Section 16 of the Water Resources Act 1991 imposes a duty on the EA to promote the conservation and enhancement of the natural beauty of inland and coastal waters and their associated lands, flora and fauna (**Hughes 1992**). Therefore in environmentally sensitive areas percentile limits can be set in addition to absolute limits. For example the EA have recommended that 80 and 50 percentile limits would be an advantage for environmentally significant discharges.

The EA is further under a duty to revoke or modify a consent in order to enable the UK to meet EU or international obligations, or to protect public health or flora and fauna dependent on the aquatic environment. However, these powers are subject to restrictions in that there is generally a period of two years from the date of a consent during which changes may not be imposed (**Hughes 1992**).

CHAPTER THREE

Phragmites australis - Ecology and Morphology

3.1 General description

Phragmites australis Cav Trin. ex Steudel (Common Reed), is one of the most widely distributed grasses. It is common in and near freshwater, brackish and alkaline wetlands in temperate zones worldwide. The northern limit of its distribution occurs in Norway and it also extends into the South Temperate Zone (**Clayton 1967**). The name *Phragmites* is derived from the Greek word for fence, *phragma*, in reference to its fence-like growth along streams (**Nature Conservancy USA, 1997**).

Some of the largest reedbeds are found in Europe, (Danube Delta and Lake Fertő) and in parts of the world people depend socially and economically on reed culture for roofing, insulation, manufacture of paper and cardboard. Thousands of tonnes of reed have been used in Romania for these purposes, (**Brix 1999**).

P. australis also provides important economic value for tourism by creating wildlife habitats which in turn encourage activities such as bird watching and fishing; it plays an important role in preventing lake and river bank erosion.

In the British Isles *P. australis* is the most important reedswamp species and is an initiator of successional development. It is intolerant of much water movement (waves or currents) and is found in two main locations; river flood plains and low-lying coastal plains intermittently or permanently flooded with shallow still water. *P. australis* is most abundant in East Anglia, the lake shores of the English Lake District, Scotland, Wales and in smaller areas of similar habitats throughout the country.

The growth of reedswamp varies with the nutrient status of a wetland. Reed stands in comparable water regimes are tall and dense in nutrient-rich habitats, and very sparse in nutrient-poor ones. Effective competitors are usually few in nutrient-poor locations, but more numerous at eutrophic sites. Consequently in the latter, *P. australis* is limited by competition, **(Haslam 1965)**.

P.australis is especially common in alkaline and brackish environments **(Haslam 1972, 1971b)** and occurs in disturbed areas as well as pristine sites. Its growth is greater in fresh water but it may be outcompeted by other species that cannot tolerate brackish, alkaline or acidic waters. Various types of human manipulation and/or disturbance are thought to promote the growth of *P.australis* **(Roman *et al.* 1984)**. For example, restriction of the tidal inundation of a marsh may lead to a change in the level of the water table, which may in turn favour *Phragmites*. Similarly, sedimentation may promote the spread of *P. austalis* by raising the level of the substrate of the marsh.

3.2 Morphology

New areas of reedbed spread predominantly through vegetative reproduction and often form dense, virtually monospecific stands. **Hara *et al.* (1993)** classify sparse stands as those with densities of less than 100 culms (vertical stems) m^{-2} and dense stands in wet sites of approximately 200 culms m^{-2} and up to 300 culms m^2 in dry areas.

Individual rhizomes live for three to six years. Buds develop at the base of the vertical rhizome in late summer and grow up to a metre horizontally (10 m in newly colonized, nutrient-rich areas) before terminating in an upward apex and becoming dormant until spring. The apex then grows upward into a vertical rhizome. The roots are found on parts covered by water and on the rhizomes which provide the plant with a large absorbent surface for obtaining nutrients from the aquatic medium. Thus the plant can extract nutrients directly from both water and soil.

Annual aerial shoots arise from the rhizomes and are most vigorous at the periphery of a stand. Here they arise from horizontal rhizomes, as opposed to old verticals **(Haslam 1972)**. Studies of reed populations in Scotland suggested that the average temperature of the warmest month determine final reed height **(Spence 1964)**. The shoots can grow up to lengths of 60 - 300 cm.

P. australis flowers and set seeds between July and September and may produce great quantities of the latter. However, in the UK, seed production is variable and in degraded sites most or all produced is not viable (**Tucker 1990**). The seeds are normally dispersed by wind but may be transported by birds. Newly opened sites may be colonized by seed or by rhizome fragments carried to the area by humans in soils and on machinery, or naturally in floodwaters. Following seed set, nutrients are translocated down into the rhizomes and the above-ground portions of the plant die back for the season (**Haslam 1968**). In winter the dead, hollow stems act as 'snorkels' and allow gas exchanges in the rhizomes. The dead stems may last for two or three seasons and then form a litter layer.

Temperature, salinity and water levels affect seed germination. Water depths of more than 5 cm and salinities above 20 ppt (2%) prevent germination (**Tucker 1990**). Germination is not affected by salinities below 10 ppt (1%) but declines at higher salinities. Maximum salinity tolerances vary from population to population; reported maxima range from 12 ppt (1.2%) in Britain to 29 ppt in New York State, USA and 40 ppt on the Red Sea coast (**Hocking *et al.* 1983**). Percentage germination increases with rising temperature from 16° to 25° C.

Dense stands of *P. australis* normally lose more water through evapotranspiration than is supplied by rain (**Haslam 1970**). However, rhizomes can reach down almost two meters below ground, their roots penetrating even deeper, allowing the plant to reach low-lying ground water (**Haslam 1970**). Frosts affect reeds temporarily but can ultimately increase stand densities by stimulating bud development (**Haslam 1968**).

3.3 Ecology

P.australis has a low tolerance for wave and current action which can break its culms (vertical stems) and impede bud formation in the rhizomes. It can survive, and thrive, in stagnant waters where the sediments are poorly aerated (**Haslam 1970**). Air spaces in the above-ground stems and in the rhizomes supply the underground parts of the plant with oxygen which also seeps into the surrounding rhizosphere creating oxidised conditions in an anoxic environment. It is this characteristic and its tolerance of salinity which allow it to grow where few other plants can survive (**Haslam 1970**). In addition the build up of litter from the aerial shoots within stands prevents or discourages other species from germinating and becoming established (**Haslam 1971c**). The rhizomes and adventitious roots themselves form dense mats that further discourage competitors. These characteristics enable *P.australis* to outcompete other species and to form monotypic stands.

Abundant litter in *P.australis* stands may provide habitat for some small mammals, insects and reptiles. In Britain, forty species of insect feed solely on reed (**Fojt and Foster 1991**). The aerial stems provide nesting sites for several species of bird. The Aquatic Warbler *Acrocephalus paludicola* is a species of international concern because both range and population has declined, (**Snow & Perrins 1998**) but it occurs in significant numbers in the autumn on reedbeds on the south coast of England. In the UK the reed warbler *Acrocephalus scirpaceus*, bearded tit *Panarus biarmicus*, marsh harrier *Cicus aeruginosus* and bittern *Botaurus stellaris* are also highly dependent on reed beds (**RSPB 1996**).

Studies conducted in Europe indicate that gall-forming and stem-boring insects may significantly reduce growth of *P. australis* (none were observed at South Milton Ley). **Mook and van der Toorn (1982)** found that yields were reduced by 25 to 60% in stands heavily infested with lepidopteran stem or rhizome borers, and although high densities of aphids may bring about reductions in *P. australis* shoot height and leaf area, they had little effect on shoot weight. Like other emergent macrophytes, *P. australis* has tough leaves and appears to suffer little grazing by leaf-chewing insects.

3.4 Reed Decline

The study of *P. australis* dates back to 1775. **M. Lunden** produced a dissertation on the species at Åbo Academy, Finland, (**Björk, 1967**). Since then various monographs and papers have investigated the ecology and growth of the plant. More recently, papers have been written on the use of *P. australis* for wastewater treatment and also on the occurrence and reasons for reed decline.

In Europe, a healthy reed belt is defined as an homogeneous, dense or sparse stand with no gaps in its inner parts, of similar height and with an evenly formed lakeside borderline. At the landward edge the reeds can be replaced by sedge or woodland communities or by unfertilized grasslands

(**Ostendorp 1989**). *P. australis* can be regarded as a stable, natural component of a wetland community if the population does not appear to be expanding.

Reedbed loss in the UK between 1945 and 1990 was estimated to be 10-40% (**Bibby *et al.* 1989**). A 1994 survey by the RSPB found that 926 sites in the UK were mostly fragmented into areas of less than one hectare. According to **Bibby and Lunn (1982)**, in England and Wales only fifteen sites exceeded 40 ha. UK reedbeds tend to be smaller than those of other countries, for example the Czech Republic and the Netherlands, but they contain a high range of species diversity per hectare and therefore possess important conservation value.

Reed decline has been detected in more than thirty-five lakes in Eastern, Central and Northern Europe (**Ostendorp 1989**). However in Mediterranean countries *P. australis* seems to be growing well and expanding its range even in eutrophic areas. In Denmark and Scandinavia new areas such as water meadows, seashores, lakes and ponds with low water levels are being colonised by reeds, (**Van der Putten, 1999**). In the Netherlands, there has been a disappearance of deep-water reeds which grow in freshwater areas and reed belts around former estuaries have also declined (**Kuijpers and Van Stockkom, 1985**).

Reasons for reed decline have been studied under the European Research Programme on Reed Die-back and Progression 1990-1994 and 1996-1999. Its conclusions indicate that eutrophication does not seem to have a direct effect on the sudden dieback of reeds but may, in combination with changing water levels, be a key factor.

Amongst the causal factors which have been studied, eutrophication and sewage disposal are often cited. For example it was postulated by Klotsli that "the pollution of our lakes is mainly (and indirectly) responsible for reed decline" (**Klötsli 1971 p. 109**). The influence of habitat on the structure of the stems of *P. australis* was first studied by **Tobler (1943)**. He found that those stems which grew in water or soils to which nitrogen had been added were thicker and possessed a smaller amount of sclerenchyma (strengthening) tissue than those growing without fertilisers.

Studies by **Markstein and Sukopp (1980)** similarly found that an increase in nitrate-N concentration in lake waters alters the strengthening tissues of reed stems. Since then **Ulrich and**

Burton (1985) and **Bornkamm and Raghi-Atri (1986)** have demonstrated the effects of nitrate and phosphate fertilisation on the anatomical features of *P. australis* in controlled laboratory experiments. **Boar *et al.* (1989)** found that changes in dissolved nutrient ratios in the waterways of the Norfolk Broadland are correlated with regression of reed swamp. They demonstrated that in controlled experiments, high N:K ratios produced a reduction in the total strengthening tissue of reed.

Disturbed carbon/nutrient balance caused by excessive nitrogen has also been suggested to cause reed die-back by **Kühl and Kohl (1993)** and **Cízková-Koncalová *et al.* (1992)**. **Dinka and Szeglet (1998)**, however, found that carbon starvation did not account for reed dieback at saline sites. Reeds which grew in water deeper than 30-40 cm were not included in the study. **Ostendorp (1989)** suggests that reed dieback usually begins with a retreat from deep water. Therefore further examination of this hypothesis is necessary.

Van der Putten (1993) found that growth of reeds can be poor on substrate rich in their own litter. Decay of *P. australis* tissue leads to the production of high concentrations of volatile phytotoxins which may affect growth. At eutrophic sites phytoxins may increase to toxic concentrations owing to the presence of blue-green algal blooms which produce toxins on breakdown. **Brix (1999)** suggests that in order to encourage regeneration of growth it may be beneficial to lower the water level to increase oxidation of these compounds.

Lissner *et al.* (1999b) carried out studies on the effect of climate on salt tolerance of different populations of *P. australis* and found that tolerance increased under conditions favouring high transpiration. Salinity also affects the decomposition process in sediments. **Mendelssohn *et al.* (1999)**, suggest that soil fertility, mainly nitrogen and phosphorus, is a major factor in determining decomposition in saline areas.

Nutrient enrichment of *Carex* sp. **(Konnings and Verschuren, 1980)** was found to reduce the aerenchymatous gas space within plants. This system allows aeration under waterlogged conditions and without oxygen rhizome tips of reed cannot survive. Increased production of litter because of higher biomass, possibly owing to nutrient enrichment, may result in increased decomposition and enhanced oxygen demand in the rhizosphere. Loss of oxygen from the rhizosphere may encourage anoxic bacteria that produce phytotoxins, **(Laanbroek 1990)**.

No differences were found in ability to assimilate experimental high nutrient loadings amongst various reed populations **(Clevering 1997)**. Differences occurred more within populations than between them. The study showed that the relationship between genetic variation and dieback is more complicated than initially assumed. No evidence was found that populations with low genetic variability were more susceptible to dieback. It is difficult for this hypothesis to be tested, because data from populations that are declining cannot be correlated because it is often not known how much variation existed before.

Work on differences between nutrient-rich and nutrient-poor sites has indicated that reed biomass increases with enrichment. However **Granéli (1983)** found that an increase in biomass in 'dense' stands of plants will ultimately produce 'thinning' as a further increase in weight or density causes excessive shading, leading to shoot mortality. This hypothesis was confirmed by his experiments in which N, P, K and sewage sludge were added to a stand of reeds. A year after fertilisation additional buds developed leading to a higher density of shoots. The following year the density and biomass decreased and it is probable that the high shoot population caused this.

Many wetland habitats receive increased nutrient loadings mainly from disposal of waste (especially sewage) and/or agricultural runoff. This study will investigate whether the conditions in which reed is known to decline occur in South Milton Ley and will build on the work of **Boar (1987)** who suggested that ratios of plant nutrients rather than absolute concentrations determine growth response.

CHAPTER FOUR

Site Description

South Milton Ley **(Figure 4.1)** is a predominantly freshwater wetland located 5 km west of Kingsbridge (UK National Grid Reference SX 685 422) in South Devon, England situated within the popular tourist region of the South Hams. It occupies a shallow coastal valley running from South Milton village south-westwards to meet the coast at South Milton Sands near Thurlestone on Bigbury Bay.

The section of the Ley between Milton Mill road and the coast **(Figure 4.2)** was originally declared a Site of Special Scientific Interest (SSSI) in 1976 and was redesignated in 1984 under section 28 of the Wildlife and Countryside Act 1981. It contains "one of the best examples of freshwater reed-bed in Devon and is particularly important for its breeding bird community and for the variety of birds using the site on passage" (SSSI citation 1984, p.2). Most of South Milton Ley is now owned and managed as a nature reserve by the Devon Birdwatching and Preservation Society (DBPS).

The Ley measures 1.5 km in length and is on average 100m wide, with a total area of 0.17 km^2. At its western end it is periodically separated from the sea by the formation of a sand bar **(Plate 4.1)**. The lake which forms behind this consists of brackish water, being subject to occasional tidal influence, but upstream the Ley contains only fresh water.

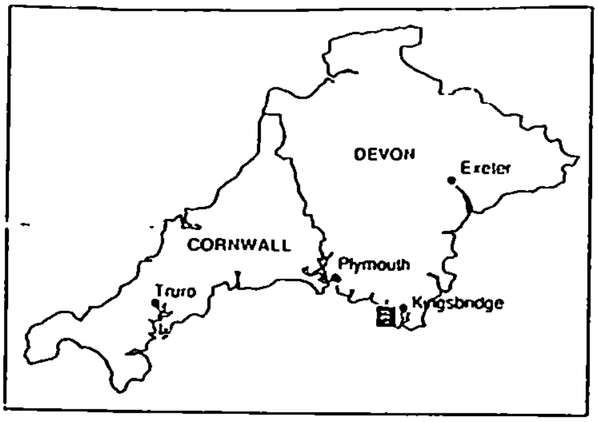
The vegetation of the lower Ley consists chiefly of the Common Reed *Phragmites australis*, while higher within the Ley a variety of fen species can be found including the following (all plant nomenclature follows **Rose 1981**):

Hemlock Water Dropwort (*Oenanthe crocata*);

Yellow Flag (*Iris pseudacorus*);

Great Willowherb (*Epilobium hirsutum*);

Reed Sweet-grass (*Glyceria maxima*);



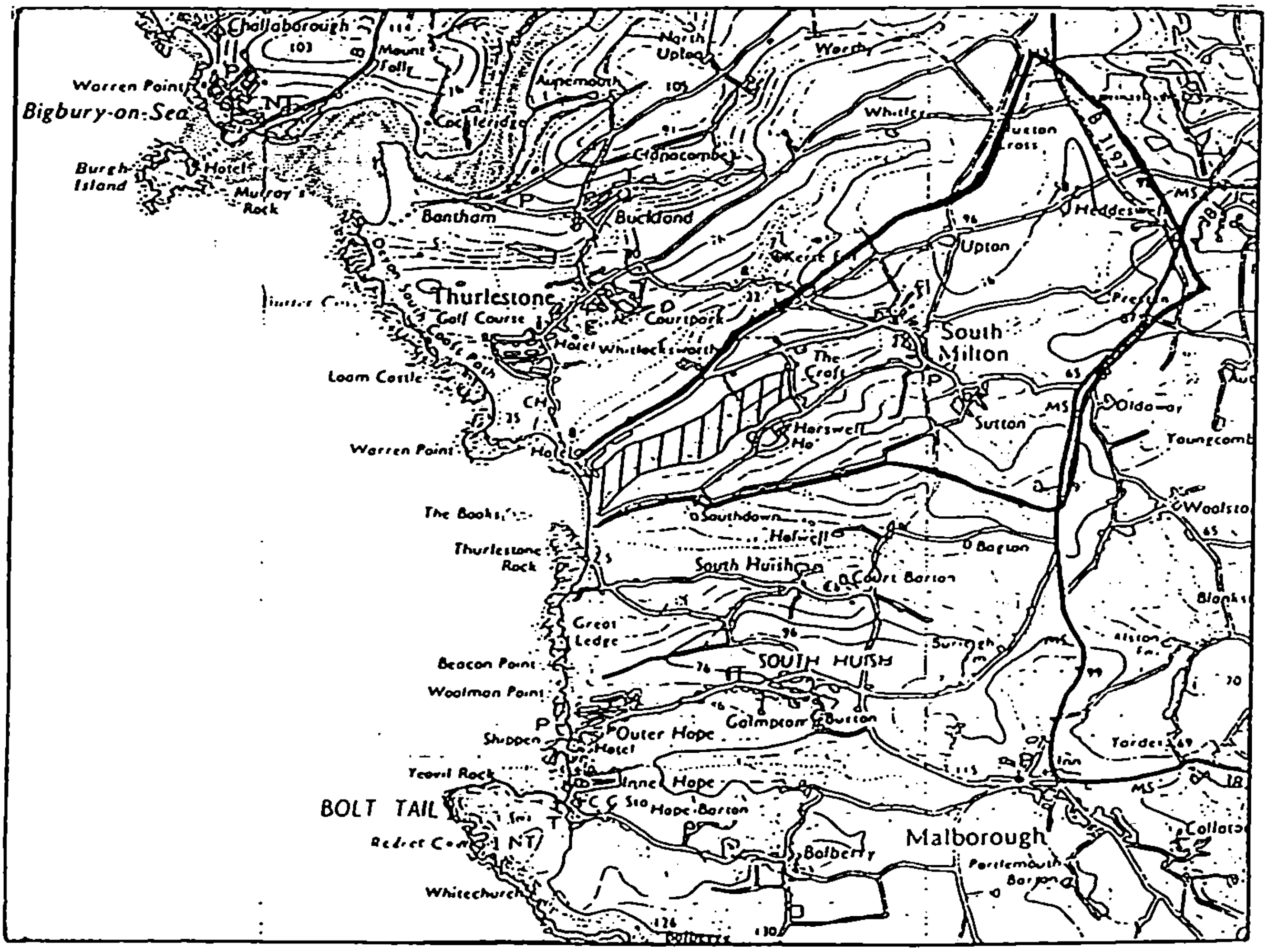


Figure 4.1

The catchment of South Milton Ley

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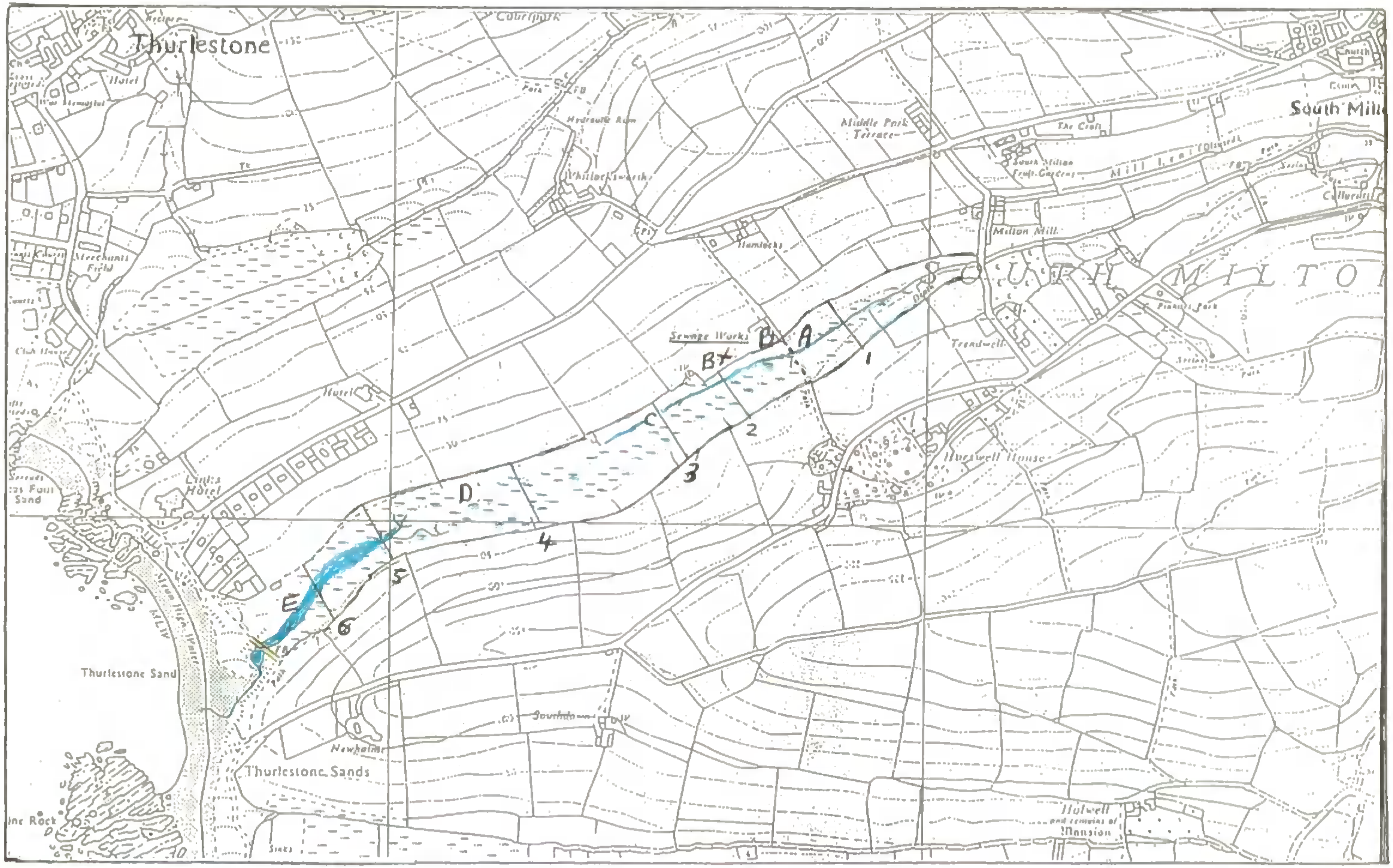

figure 4·2 southmilton ley

transects 1-6
sampling sites a-e

Stands of trees and shrubs also occur in the upper areas including:

Willow (*Salix cinerea*);

Hawthorn (*Crataegus monogyna*);

Alder (*Alnus glutinosa*).

The ecotone between the reedbed and the surrounding agricultural land is colonised by a mixture of coarse grasses and herbs such as members of the Umbelliferae and the Leguminosae which provide an additional habitat and food source for the birds.

The catchment of South Milton Ley (**Figure 4.2**) covers 5.4 km^2. The geology is principally Devonian slaty mud and siltstones overlain by well-drained fine loamy and silty soils. The area is mainly used for agriculture, which is mostly pasture with some arable rotation; 0.15 km^2 is occupied by woodland. Included in the catchment are the villages of South Milton, Sutton and Upton, which together with farm hamlets occupy a total area of 0.24 km^2. South Milton village contains a population of 396 (**Census, 1991**).

4.1 Historical Data

An aerial photograph of the Ley taken in November 1945 (**Plate 4.2**) provides information concerning the uses of the area at that time. As now, the surrounding land was used for mixed arable agriculture while there is evidence of an old field pattern within the Ley itself in the form of remnants of hedgerows. The shrubs which are now growing in the Ley appear to be derived from those old hedgerow plants and do not indicate that succession is in progress. This suggests a degree of stability. South Milton Stream then occupied a more central position in the upper Ley and seems to disappear into the reed-bed higher up than it does now. The sand-bar was closed at the time the photograph was taken.

Plate 4.1

Impounded lake at South Milton Sands

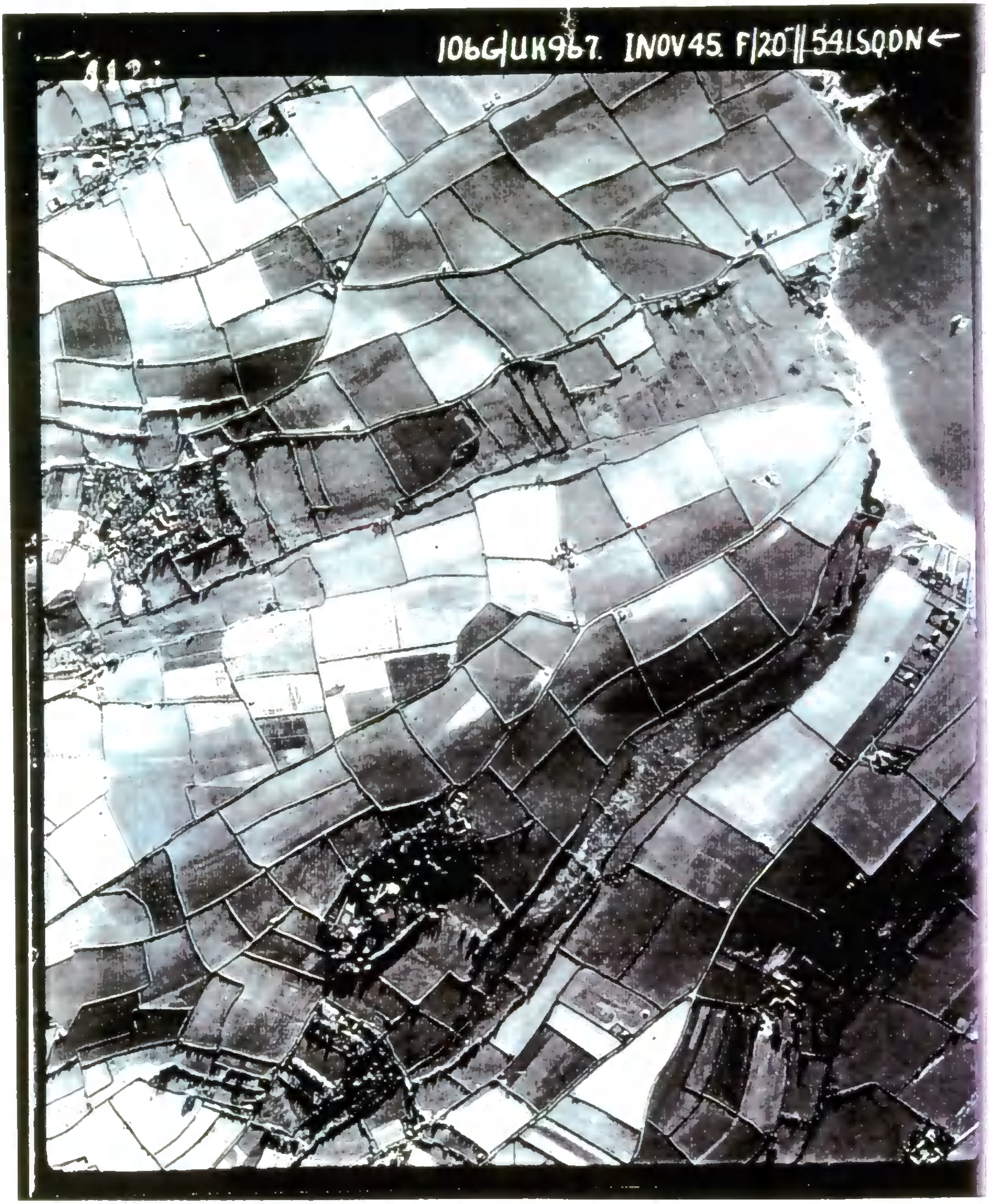

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PLATE 4·2

The 1813 Old Series Ordnance Survey map **(Harley 1964)** shows that in 1809 when the area was surveyed, South Milton Stream emptied into a tidal creek and did not form part of a wetland **(Figure 4.3)**. Subsequent flooding of the area owing to sand-bar formation has apparently caused the Ley to develop as it is today.

4.2 The Hydrology of South Milton Ley

The hydrology of the Ley consists of a combination of systems which operate independently but which interact in order to create effects which are both seasonal and stochastic. In particular, the sand bar which forms during certain weather conditions can quickly cause flooding throughout the lower Ley.

The main freshwater input to the upper Ley is South Milton Stream **(Figure 4.2)**. Its source is a spring located in the grounds of a residential property (GR: 70994432). The stream flows south-west for 5 km across agricultural land, through South Milton village and enters South Milton Ley along its northern edge. At normal flows it is confined to a dredged channel running for about 1 km before disappearing into the reeds. The stream receives storm runoff from road drains before entering the Ley. In addition both the stream and Ley are recipients of runoff from the surrounding agricultural land. There have been a number of pollution incidents over recent years caused by slurry or other farm waste entering the stream. A further, shallower ditch runs along the southern edge of the Ley **(Figure 4.2)**. This was dug in 1977 in order to supply the pond by the bird hide located in a mid point along this southern boundary.

Further sources of water to the Ley include lateral springs and seepage zones through the underlying slates and shales. Only two springs can be clearly identified, although the nature of the terrain and vegetation suggest that others may exist. In addition, areas of saturated ground within the higher Ley were apparent during dry periods in the summer of 1992, and these would seem to be indicative of seepage.

Tuffland
Combe
Borough
Chance Combe
Dameral Combe
Langston
Renton
Holwell
St. Anne Chapel
Ducks Mill
Efford
Marwell
Bigbury Parsonage
Houghton
Hingston
Bigbury
Mill
Ringmore
Aveton Gifford
Knap Mill
Hatch
Stodbury
Newton
Etson
Hexdown
North Upton
Fishery
Mount Folly
Borough Island
Whitley's
Hedgwell
Bantham
Buckland
Upton
Thirlestone
South Milton
Mill
Horsewell Ho.
Holwell
Sutton
Thurlestone Rock
South Hewish
Bagton
Burleigh
Galmpton
Rugwell
Withymoor
Hope
Nth. Bolbury
Marlborough
Hope Cove
Bolt Tail
Windsor
Portlemouth
South down

FIGURE 4·3

4.3 Sand-bar Formation

South Milton Sands, which lies at the coastal end of the Ley, is a west facing storm beach which is subject to sand-bar formation (**Plate 4.3**). This can occur at any time of year following a period of gale force winds from the west or southwest. The height of the bar depends upon the wind speed and direction and the nature of wave motion. Once the sand-bar has formed, a lake develops behind it as incoming fresh water flowing through the reed-bed accumulates. The depth of the lake is determined by the height of the sand-bar. An additional input to the lake is seawater which sometimes washes over the bar when high tide coincides with strong winds (**Plate 4.4**).

Whilst the lake is impounded, the main output of water from the Ley is by seepage through the sand-bar.

Formation of a sand-barrier leads to the creation of a large lake, the pressure of which can cause a sudden breach in the bar. The lake will then empty rapidly, the force of the water producing a deep gully across the beach (**Plates 4.5, 4.6 and 4.7**). The deeper the gully, the longer the bar will take to reform; for this reason the breaching of a high bar will tend to be followed by a long period of low water, while conversely a lower bar will often survive longer. Hence the irregular nature of the flooding of the Ley which is a product of the unstable sand-bar has retarded ecological succession and maintained the conditions in which the reed-bed has flourished.

4.4 South Milton Sewage Treatment Works

In 1960 a sewage treatment works was commissioned which served South Milton village and which discharged its treated effluent into South Milton Stream within the Ley (UK National Grid Reference SX 6860 4228; **Figure 4.2**). The works dealt with the domestic wastewater for a peak residential and tourist population of 340 persons (**SWWSL, 1990**). It included both primary settling and secondary biological treatment.

Plate 4.3: Sand-bar and impounded lake at South Milton Sands

Plate 4.4: Sea at South Milton Sands encroaching towards sand-bar

Plate 4.5: Impounded lake at footbridge when sand-bar at a high level

Plate 4.6: Lake at footbridge after sand-bar had broken

In 1992 a new sewage treatment works was opened which replaced the original plant and in addition now served the resident and tourist population of Thurlestone, whose wastewater had previously been discharged untreated into the sea off Thurlestone beach **(Plate 4.8)**. The expanded facility is designed for a maximum summer population of 1,500 by the year 2001. The effluent from the new plant continues to be discharged into South Milton Ley along the same channel. The plans for the new works were prepared by W S Atkins Consultants Limited, Consulting Engineers, who also supervised its construction and were commissioned by SWWSL to undertake a "baseline environmental survey" of South Milton Ley. Their proposals were submitted by SWWSL to the National Rivers Authority (now the Environment Agency) in January 1991.

In view of the acknowledged environmental sensitivity of the Ley, the discharge consent eventually granted by the then NRA incorporated the requirement that there be no future increase in pollutant or nutrient loadings above those generated by the old plant. To comply with this, SWWSL have included a constructed reed-bed as part of the works. This occupies an area of 1,678 m^2 and has been planted with *Phragmites australis* **(Plate 4.9)**. It is designed to act as a tertiary treatment plant which should remove excess nutrients from the wastewater prior to discharge. Conditions governing operation of the storm tank, which was not covered by the consent for the old works, are now included within the parameters of the consent.

Once the plans for the new works were submitted to the NRA, a number of objections were lodged by local residents, by the DBPS and by English Nature (EN). EN questioned whether the works with the constructed reed-bed would be capable of achieving the required effluent quality and voiced concern about the effect of an increased nutrient loading on the Ley. They also had doubts about the calculation of the 95 percentile limits for nitrogen and phosphorus and their respective loads. They believed that the consent calculations were based on limited data and an inadequate knowledge of the hydrological system of South Milton Ley.

Plate 4.7: Water flow across South Milton Sands after the sand-bar had breached

Plate 4.8: South Milton Sewage Treatment Works with RBTS in centre and Ley beyond

Plate 4.9

Reed bed treatment system at South Milton sewage treatment works

The NRA issued a provisional consent to discharge in June 1991 for comment, but in August 1991 this was revised and the parameters concerning phosphorus and effluent flow were raised. EN then decided that these levels would cause damage **(EN 1992)** and requested the Secretary of State for the Environment to call in the proposals, which he declined to do. The final consent was issued in February 1992 and came into effect in June 1992 **(Appendix One)**.

4.5 The Consent to Discharge

As already stated the consent calculations for the South Milton works are based on the objective of no increase in nutrient loading compared with that received from the old sewage treatment works. The loading is defined as a product of effluent quality and discharge volume.

The current consent as issued by the NRA on 2 April 1993 is detailed as follows:

Flow discharge

The maximum rate of discharge should not exceed 12 litres s^{-1};

Dry weather flow should not exceed 320 m^3 in any period of 24 hours

(320 m^3 24 h^{-1} ≡ 3.7 litres s^{-1}).

Effluent quality

The maximum load discharged over any single 24-hour period should not be in excess of:

2 mg l^{-1} of ammoniacal nitrogen expressed as nitrogen;

11 mg l^{-1} of phosphate expressed as total phosphate (≡ 3.5 kg d^{-1} @ 3.7 litres s^{-1}).

Column two in the table included in **Appendix One** lists the maximum permitted number of samples which may fail to conform to numerical limits from a series of samples taken in any year (column 1). This refers to the above parameters.

The following levels should not be exceeded at any time:

In excess of 4 mg l^{-1} ammoniacal nitrogen as nitrogen (≡ 4.2 kg d^{-1} @ 12 litres s^{-1}).

In excess of 22 mg l^{-1} phosphate expressed as total phosphate (≡ 22.8 kg d^{-1} @ 12 litres s^{-1}).

The 1992 consent was revised by the NRA in 1993 so that the same figures for flow conditions and quality limit values then became expressed as mg l^{-1}. Total oxidised nitrogen (TON) limits were not included in the 1993 consent although collection of TON data by the EA continued until 1996.

CHAPTER FIVE

Study of Hydrology

5.1 Field sampling sites

The selection of sampling sites depended on access, easy relocation and that they should be representative of the habitats of the Ley. Five major vegetation zones were recognised by **Latimer (1991)** and it was decided to use these for water chemistry analysis, collecting data on *P. australis,* and recording hydrological measurements.

Zone One **(Figure 4.2)** is that part of the Ley upstream from the STW and consists of mixed fen and stands of *P. australis.* Reed mace *(Typha latifolia),* Great hairy willow herb (*Epilobium hirsutum*) and Hemlock water dropwort (*Oenanthe crocata)* also occur. The second Zone is adjacent to the STW and is crossed by a public footpath. The original sewage outfall (before the extended works were built) emptied into the stream at this point. Nettle (*Urtica dioica*) and reed canary grass are the main species present and drier conditions are indicated by the absence of *P. australis.* Zone Three contains predominantly *P. australis* stands which begin abruptly at the end of Zone Two. This site contains a dry litter layer and trees such as Willow (*Salix cinerea*), Hawthorn (*Crataegus monogyna*) and Alder (*Alnus glutinosa*) grow within this area. The community changes to a wetter type in Zone Four where tall stands of *P.australis* predominate. Water depth increases towards the centre and southern part of the zone. The *P. australis* community continues into the fifth zone where it has colonised areas with sandy substrate. Brackish water influence is indicated by the appearance of coastal species such as Sea Club Rush (*Scirpus maritimus*) and Sea Spurrey (*Spergularia marina).*

One transect was established within each zone **(Figure 4.2)**. The position of these depended on access across the Ley and on each providing a sample of plant growth within the zone. Five 1 m^2 plots were positioned twenty metres apart along each transect. Where an existing path was used, plots were placed on alternate sides of the track away from the path in order to avoid disturbance of reed through trampling.

i) Transect One:

National grid reference SX 689 425. 200 m upstream from STW outflow.

ii) Transect Two:

National grid reference SX 687 423. 75 m upstream from STW outflow.

iii) Transect Three:

National grid reference SX 685 422. 3 m downstream from STW outflow.

iv) Transect Four:

National grid reference SX 681 429. 400 m downstream from STW outflow.

v) Transect Five:

National grid reference SX 679 419 600 m downstream from STW outflow.

vi) Transect Six:

National grid reference SX 678 417. 800 m downstream from STW outflow. This transect was located either side of the channel at the seaward end.

Surface water samples were collected for nitrogen and phosphorus analyses at the following sites **(Figure 4.2)**. The choice of these locations depended on the difficulty of gaining access through the reedbed which in some sections was too waterlogged to be traversed to the central open water. It was decided, therefore, to locate the sites at points along South Milton Stream where a representative assessment of changes in nutrient concentration could be obtained from the inflowing water.

i) Site A - (Diffuse source).

Immediately below the public footbridge upstream of the sewage treatment works (UK National Grid Reference SX 687 423). This site was chosen as the water entering the Ley at this point has passed through the catchment and therefore contains the major diffuse sources of nitrogen and phosphorus.

ii) Site B - (Point source).

Effluent inflow into the RBTS at South Milton STW (UK National Grid Reference SX 686 424). No additional point sources have been identified in the catchment apart from South Milton STW **(Houston 1992)**.

iii) Site BX - (Point source).

Effluent outflow from the RBTS at South Milton STW (UK National Grid Reference SX 686 424)

iv) Site C

South Milton Stream at the RBTS outflow (UK National Grid Reference SX 685 423).

v) Site D

Limit of the tidal area which extends into the Ley (UK National Grid Reference SX 679 419).

vi) Site E

On the edge of the main channel which flows out to the sea (UK National Grid Reference SX 678 417). The location of this point depended on access to open water through the stands of *P australis*.

Subsurface water depth measurements were undertaken during 1996 from Plots Two, Three, Five and Six along all transects except number Five (which was inaccessible); **Figure 4.2**. Chemical analysis was carried out on subsurface water from Plots Three and Six in the same year and from all plots in August 1995 (during reed fieldwork).

5.2 Methods

In order to calculate a water budget and establish the residence time for water in the Ley, the following individual components of hydrology were studied:

5.2.1 Streamflow

Streamflow measurements were recorded at South Milton Stream, Site A every two weeks (**Figure 4.2**) by the velocity-area technique using a current meter (**Brassington 1988**). This method was employed in preference to a weir because of the unstable river substrate which would have made installation difficult. The cross-sectional profile was determined by measuring the depth of water at intervals across the stream. Stream velocity was measured in each segment at 0.6 of the depth below the surface using either a Braystoke B F M 002 or an Ott C.2 "10.150" current meter. Total discharge was calculated by summing the series of segments multiplied by the velocity which had obtained in each profile (**Gregory and Walling, 1973; Van Vlymen 1979**).

Flow discharge at Site E was determined after the sand bar had been breached. Measurements were recorded after an outward channel had developed from the Ley to the sea. The flow was calculated by recording several timings of a small float over a measured distance and by multiplying the average velocity by the cross-sectional area (**Brassington 1988**).

Although the underlying geology of the Ley causes lateral seepage zones and springs to occur these were only apparent after wet weather and as no flow was discernible, measurements were not possible. In order to determine whether transverse flux from the southern longitudinal drain may be significant in maintaining wetland conditions, four piezometers, in the form of 2-m length drainpipes were installed along each of the five transects (**Figure 4.2**). Head conditions and hence hydraulic gradients could be defined from the water level readings.

Sewage effluent leaves the RBTS via a monitored v-notched weir. This is connected to the outlet pipe which is submerged and cannot be used for flow monitoring. Twice weekly data on effluent flow from site BX were provided by the Environment Agency owing to the difficulty of obtaining access to the sampling well and outflow pipe, however effluent samples could be taken from a holding trough at the end of the RBTS which contained effluent before it entered the v-notched weir.

During times when the sand bar was present the level of water at site E was recorded by reading a height gauge which had been marked on the footbridge. This information was then correlated with stream flow data and used to provide an estimate of the amount of water in the Ley.

Weather data were obtained from the nearest appropriate weather station at Slapton Ley Field Centre. These were used to calculate direct rainfall onto the Ley and also evaporation rates. This information together with the streamflow data and sand-bar seepage rates was used to determine changes in storage and water balance of the Ley.

5.2.2 Outflow seepage through sand-bar

The flow of water through a sand-bar can be said to conform to the principles of groundwater movement through a free aquifer composed of unconsolidated materials (**Van Vlymen 1979**). The capacity of sediment material to transmit water under pressure is related to its permeability and is defined by Darcy's Law.

An estimate of outflow seepage through the sand-bar was calculated using this law which states that for saturated conditions the rate of flow of water through a porous medium is proportional to the slope of the water table (hydraulic gradient; **Ward and Robinson 1989**).

The formula $Q = K\ I\ A$ is used in applying Darcy's Law where K is hydraulic conductivity. Defined as the volume of water that will flow through a unit cross-sectional area in unit time under a unit hydraulic gradient; I is the hydraulic gradient and A is the cross-sectional area.

Hydraulic conductivity (K) of the sand-bar was determined in the laboratory by using a constant-head permeameter (**Todd 1980**). This procedure was chosen as the most practical owing to the cost of alternative methods such as tracer or pumping well tests.

Changes in hydraulic gradient (I) at minimum and maximum sea levels have important effects on velocity levels and flow pressures (**Van Vlymen 1979**). Also the velocity of flow through the barrier increases with Ley levels. It was assumed that as the Ley is always above sea-level the gradient was seaward. In the absence of specific data as to fluctuations of permeability, the measurement of hydraulic gradient was based on maximum Ley level and on mean sea-level. The gradient was comparable with that estimated by **Van Vlymen (1979)** for the shingle barrier at Slapton Ley which is the same height above sea-level as the sand-bar at South Milton Ley.

The cross-sectional area of the barrier was measured and multiplied by K and I to give the flow of water through the bar. The hydrological output from the system could then be calculated using seepage and evaporation figures and this could be balanced against the inputs of rainfall and streamflow.

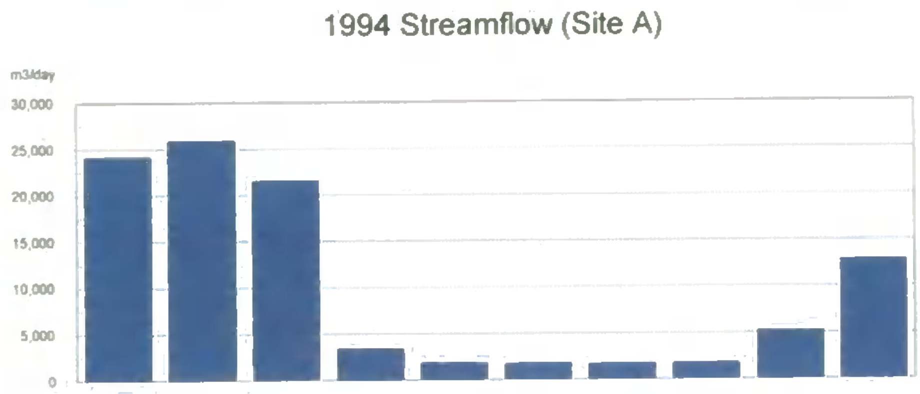
5.2.3 Study of sand-bar formation

Formation and breaching of the sand-bar are important factors to monitor as they control whether the Ley functions as a river or a lake. The occurrence of storm weather events and tidal fluctuations which affected the sand-bar were therefore noted and the use of wind speed and direction information from Slapton Ley weather data enabled a correlation to be made between the incidence of gale-force winds from the SW to NW and the formation of the barrier.

Historical background information as to the movement of the bar and changes in the extent of the Ley was obtained from old aerial photographs and anecdotal evidence from members of the Devon Birdwatching and Preservation Society.

5.3 Results

5.3.1 South Milton Ley streamflow (Site A) 1994-1996

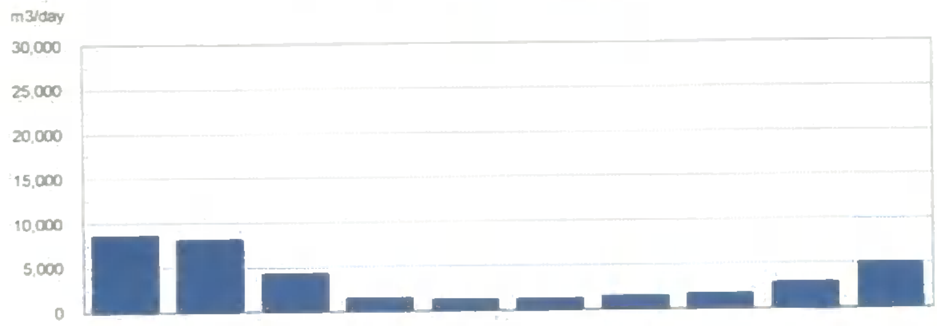


	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
■	24,192	25,920	21,600	3,456	1,901	1,771	1,711	1,769	5,219	12,965

Figure 5.1

Figures 5.1 to 5.3 represent South Milton mean daily streamflow (site A) for the years 1994 to 1996. The highest measurement (25,920 m3 d^{-1}) was recorded in April 1994 and the lowest (1,296 m3 d^{-1}) occurred in July and August 1995. Average streamflow for 1994 was 8,468 m3 d^{-1}; for 1995, 3,675 m3 d^{-1} and 1996 5,418 m3 d^{-1}. The year 1994 (**Figure 5.1**) follows a similar seasonal pattern to that of 1995 (**Figure 5.2**), whereby measurements of high streamflow were registered in April, May, November and December and low flows from June to October. In contrast during 1996 (**Figure 5.3**), high values were recorded in May and August and low measurements were taken early in the year (March and April).

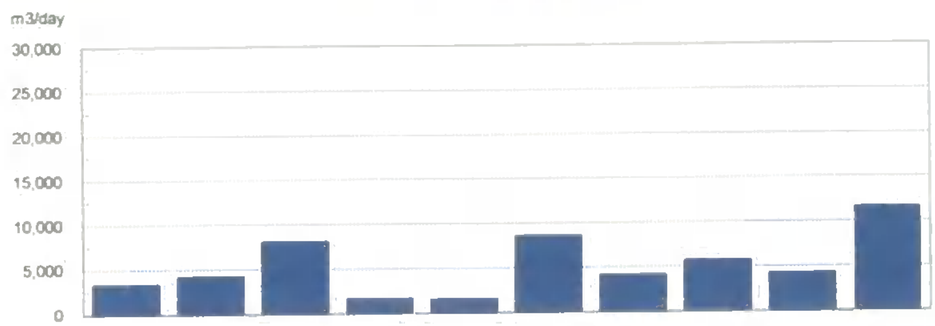
1995 Streamflow (Site A)



	March	April	May	June	July	August	Sept	Oct	Nov	Dec
■	8,666	8,208	4,320	1,555	1,296	1,296	1,495	1,737	2,989	5,184

Figure 5.2

1996 Streamflow (Site A)



	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
■	3,456	4,320	8,208	1,728	1,650	8,640	4,251	5,858	4,320	11,750

Figure 5.3

5.3.2 Piezometer Results for 1996

Table 5.1 records piezometer readings for the period February to December 1996 for Plots Two and Three (northern edge of the Ley) and Five and Six (southern edge) along Transects One to Six. Missing values along some of the transects have occurred because of dry readings or inaccessibility owing to high water levels.

	Transect One				Transect Two				Transect Three				Transect Four				Transect Six			
Plot	*2*	*3*	*5*	*6*	*2*	*3*	*5*	*6*	*2*	*3*	*5*	*6*	*2*	*3*	*5*	*6*	*2*	*3*	*5*	*6*
Feb	31	27	64	50	100	70	117	70	75	75	70	65	105	100	105	105			30	30
March	14	10	54	50	92	80	76	70	97	90	97	67	164	162	115				26	26
April	18	16	50	45	100	90	90	75	84	72	85	83	150	145	102	100			40	40
May		21	21	20	94	90	100	98	75	70	33	30	86	86	87	84			10	10
June				92	90	42			20	27	42	40					20	20	27	27
Aug	38	38	74	70	64	145	144	140	15	10	62		128	145	147	100	15	15	20	20
Oct	9	85	83	80	116	78	110	83	100	110	90	90	145	150	150	135	150			
Nov	18	18	100	116	89	89	130	125	64	94	118	95	183	168	191	157				
Dec	34	30	35	85	88	120	94	90	118	114	122	120	134	140	111	100				

Water depth in cm

Table 5.1: piezometer readings 1996

Results from sites north to south across each transect produced high values for the southern side of the Ley for all months except October. Plots on the northern edge recorded higher values along transect four for March, April, November and December.

Transects Two and Four produced the highest readings for Plots Two, Three, Five and Six and the lowest were recorded in the same plots along Transect One and Six. Results ranged from 9 cm at Plot Two, Transect One in October to 191 cm at Plot Five, Transect Four in November. Highest overall values were recorded in February, March and April at the beginning of the year and in the latter months of August, October, November and December. The lowest occurred in May and June.

5.3.3 Water balance results 1994-1996

Rainfall inputs to the Ley were calculated using Morecs mean effective precipitation data 1988 - 1998 which takes into account evapotranspiration for grassland. .

Tables 5.2 to 5.4 represent the water balance of South Milton Ley for the three study years for a six month period from July to December. During 1994 the water balance was positive (inputs exceed outputs) for all months except for November where outflow exceeded inflow. Effluent discharge from the STW represented 20.5% of the total inputs in August but fell to 2.3% in December. South Milton stream comprised 75% of total inflow in August and 92% in December. Rainfall was recorded as 3% of total inputs in August and 5% in December. The highest total inflow and outflow occurred in December and the lowest in August.

m^3d^{-1}	INPUTS				OUTPUTS				
	Rainfall	STW	S Milton Stream	TOTAL	Evap	Seepage[1]	Seepage[1] & outflow[2]	TOTAL	Net Inflow
Jul	-	11,249	58,925	70,174	4,821	66,243	-	71,064	-890
Aug	-	14,840	51,402	66,242	5,083	58,799	-	63,882	2,360
Sep	7,361	12,345	52,216	71,922	3,200	49,227	-	52,427	19,495
Oct	16,422	7,617	53,758	77,797	1,683	42,701	-	44,384	33,413
Nov	18,173	10,900	274,778	303,851	-	-	343,160	343,160	-39,309
Dec	36,040	10,506	427,600	474,146	-	-	281,777	281,777	192,369

[1] Estimated using Darcy's law
[2] Estimated from observed flow

Table 5.2: Water budget for 1994 (six months)

During 1995 (**Table 5.3**) the water balance was positive for all months except December. South Milton Stream accounted for the greatest percentage of total inputs, 84% in July and 83% in December. Rainfall represented the smallest inflow (3% in July and 14% in December) but exceeded evaporation from open water throughout all months. The sand-bar was closed from July to November but there was a net water loss from the Ley when it was breached by a storm in December.

m^3d^{-1}	INPUTS				OUTPUTS				
	Rainfall	STW	S Milton Stream	TOTAL	Evap	Seepage[1]	Seepage[1] & outflow[2]	TOTAL	Net Inflow
Jul	-	6,696	40,176	46,872	5,230	42,154	-	47,384	-512
Aug	-	9,374	40,176	49,550	4,923	44,250	-	49,173	377
Sep	-	12,183	44,764	56,947	2,850	43,159	-	46,009	10,938
Oct	1,241	7,366	53,836	62,443	1,793	46,210	-	48,003	14,440
Nov	16,371	9,849	89,683	115,903	1,126	48,364	-	49,490	66,413
Dec	14,331	6,696	136,491	157,518	-	-	250,195	250,195	-92,677

[1] Estimated using Darcy's law
[2] Estimated from observed flow

Table 5.3: Water budget for 1995 (six months)

Table 5.4 records a positive inflow to the Ley for 1996 for all months. South Milton stream again accounted for the highest percentage of total inflow from July to December. Lowest streamflow occurred in July (98% of total input) and highest in December (94% of total inputs). Rainfall represented a similar percentage of inflow as in 1994 (2% in July and 6% in December). Effluent discharge was lowest in September and highest in November.

The monthly budgets indicate that the Ley is 'streamflow - dominated'. Highest monthly streamflow input over the study period occurred in November and December 1994 and the lowest flows were recorded in every month of 1995.Throughout all years evaporation and rainfall are low in comparison with other components but their influence in times of drought may be significant.

m^3d^{-1}	INPUTS				OUTPUTS				
	Rainfall	STW	S Milton Stream	TOTAL	Evap	Seepage[1]	Seepage[1] & outflow[2]	TOTAL	Net Inflow
Jul	-	16,070	51,150	67,220	5,000	42,100	-	47,100	20,120
Aug	-	12,589	267,840	280,429	4,900	43,100	-	48,000	232,429
Sep	-	5,703	127,524	133,227	2,987	46,500	-	49,487	83,740
Oct	1,615	9,108	181,595	192,318	1,630	43,100	-	44,730	147,588
Nov	26,724	41,472	129,600	197,796	1,121	55,300	-	56,421	141,375
Dec	9,622	7,499	364,262	381,383	-	-	300,192	300,192	81,191

[1] Estimated using Darcy's law
[2] Estimated from observed flow

Table 5.4: Water budget for 1996 (six months)

5.3.4 Residence times 1994 - 1996

The delay between input and output of a unit mass of water (hydraulic retention) depends on storage capacity of a water body relative to input. From a study of the mean depth, area and shoreline configuration of the Ley, the volume of water present was calculated for minimum and maximum volumes **Table 5.4.**

Table 5.5 displays the calculated residence times for the four states of the Ley (sand-bar open and closed, streamflow high and low). Residence time for 1994 and 1995 was 11 days when the sand-bar was closed. However in 1996 this was reduced to 4.7 days. During 1995 the residence time when the sand-bar was open was 2.2 hrs owing to high summer streamflow. In 1994 and 1996 reduced summer streamflow produced the lower residence time of 1hr.

1994	
High stream flow Sand-bar closed Residence time 11 days	Low stream flow Sand-bar closed Residence time > 11 days
High stream flow Sand-bar open Residence time 1 hour	Low stream flow Sand-bar open Residence time > 1 hour

1995	
High stream flow Sand-bar closed Residence time 11 days	Low stream flow Sand-bar closed Residence time > 11 days
High stream flow Sand-bar open Residence time 1 hour	Low stream flow Sand-bar open Residence time > 1 hour

1996	
High stream flow Sand-bar closed Residence time 4.7 days	Low stream flow Sand-bar closed Residence time > 4.7 days
High stream flow Sand-bar open Residence time 1 hour	Low stream flow Sand-bar open Residence time > 1 hour

Table 5.5: Annual residence times

	0.17 km^2
Length	1.5 km
Mean width	100 m
Mean depth	1.19 m
Max depth	3.33 m
Max volume	24,810 m^3
Min volume	1,158.3 m^3
Seepage through sand-bar	1,451 $m^3\ d^{-1}$

Table 5.6: Morphometry of South Milton Ley

5.4 Discussion

South Milton Ley has been impounded for most of the study period and so during this time the system has acted as a lake. It has been influenced by high inflows from the stream and from rainfall, which have led to a net increase in water volume. The volume has been supplemented by treated sewage effluent, springs and periodic influx of seawater over the sand-bar during storms.

The length of time during which the Ley acts as a lake or a river, and its periodic flushing when the sand-bar breaks, are of prime importance to the nutrient budget of the system. During the period of study the Ley was 'flushed' at the end of each year when fluxes of both nitrogen and phosphorus were high. Solutes were then transported rapidly through the system. However the timing of these incidents is highly variable and the sand-bar may stay intact throughout the season when fluxes are high.

It appears from weather data and from anecdotal evidence, that the conditions which cause sand-bar formation are likely to occur at some time each year. The winds needed to form a bar are those from the SW through to NW during suitable storm conditions and these generally occur in the autumn and winter months. Once the bar is in place, residence time in the Ley will increase and the opportunity for removal reactions between nitrogen and phosphorus and wetland soil would be reduced as the water level rises **(Nichols 1983)**.

The rate of seepage through the sand-bar is of fundamental importance to the hydrology of the Ley and represents the main recorded output from the impounded system. Although average losses have been assumed in this study, seepage rates will vary as tidal cycles and water levels affect flow pressure, and hence the velocity of water flow. At times of low streamflow and depleted water levels in the Ley, seepage rates through the bar will be less and this will serve to increase the retention time of water in the system.

Towards the end of the study years conditions of high rainfall and winds combined with spring tides further raised the water level in the Ley. Pressure of the enlarged water volume causes the sand-bar to be breached. This event transforms the system from a lake to a river so substantially increasing the rate of water flow and decreasing the residence time.

5.4.1 Water Balance

South Milton Stream **(Figure 4.2)** conveys the largest input of water to the system. Field drains situated on the northern side of the Ley also help to maintain a baseflow. The stream is an artificial drainage channel and its course in the higher part of the Ley (Zone One, **Figure 4.2**) bears little resemblance to the former meandering natural stream. Piezometer data which were collected during 1996 **(Figure 5.4)**, indicates that Transect One was the driest region, whereas it may have previously been much wetter.

In terms of water volume, therefore, the habitat is maintained by an east-west flow, but for water level, the near surface local flow from north-south and south-north is important in preserving wetland character.

Seepages from the Lower Devonian slates and shales are classified as minor aquifers by the Environment Agency and therefore volumetrically can only contribute a minor part of the total water flux in the Ley, but in the summer they may help considerably in maintaining a semi-constant head. **Figure 5.4** demonstrates by the results of fairly uniform piezometer readings across the Ley and higher values for Transects Two and Three, Plots Five and Six during August, that the southern field drain **(Figure 4.2)** provides a feed of water northwards into the reedbed.

During the study period the Ley was 'flushed' during November and December when fluxes of nitrogen and phosphorus were high. Solutes would then have been transported rapidly through the system. However the timing of these incidents is highly variable and the sand-bar may stay intact throughout the season when fluxes are high.

During the study period recorded inputs to the system exceeded outputs except for July 1994 and 1995 and November 1994. Various factors could have contributed to this result. In November 1994 the sand-bar was completely destroyed leaving a wide channel across the beach. By the following month the sand-bar had started to reform and streamflow output was reduced. During December 1995 and 1996 the sand-bar was breached again but part of it remained thus reducing measured outflow.

Calculation of the rate of water seepage from the impounded system (whilst the bar was intact) was undertaken on the assumption that this was limited to percolation through the sand-bar. Impounded water is in contact with sand over a much larger area than that of the bar itself, especially beneath the dunes to the north of the bar **(Plate 4.1)**. Although the pathway via this route to the sea is less direct than through the sand-bar, it is possible that water also leaves this way. A further outlet from the system could take the form of loss to groundwater through seepage zones. The net outflow in July 1994 and 1995 could be a result of a soil moisture deficit following dry months causing some degree of recharge before streamflow increased.

CHAPTER SIX

Study of Nutrient Enrichment at South Milton Ley

6.1 Water chemistry - speciation of nitrogen & phosphorus in natural waters

6.1.1 Phosphorus

Phosphorus is often the first element to limit biological activity. It plays a major role in biological metabolism **(Deevey, 1970)** and occurs in natural waters in both particulate and dissolved forms, the latter being defined as the fraction which will pass through a 0.45 micron filter **(Peat *et al.* 1995)**. Total dissolved phosphorus (TDP) is soluble, mobile and therefore biologically available. This fraction can be divided further into dissolved organic and inorganic phosphorus, (DOP and DIP). DOP is comprised of high molecular weight colloidal species and DIP of orthophosphates (the most significant form of inorganic phosphorus) and condensed phosphates.

Dissolved fraction	Particulate fraction
Orthophosphates	Organic PO_4
Condensed phosphates	Mineral PO_4
Organic phosphates	Organic/inorganic precipitates
Colloidal phosphates	Organic/inorganic adsorbtion

Table 6.1: Speciation of phosphorus

A large proportion of the phosphorus present in fresh waters is bound in organic phosphates. About 70% of the organic phase exists in particulate form and the rest as dissolved colloidal phosphorus, **(Wetzel 1983)**. Organic particulate forms of the element are less bioavailable because they are bound within or attached to organic complexes or precipitates. However, some components of dissolved organic and condensed phosphates also particulate fractions may be used by algae and bacteria after hydrolysis by exocellular enzymes, hence TDP and particulate phosphorus may be potentially bioavailable (Peat *et al.* 1995). Particulate phosphorus can be present as animal, plant or bacterial material, weathered minerals or adsorbed onto the surface of clay or mineral particles. Phosphorus is extremely reactive and interacts with many cations. Under oxidising conditions it forms relatively insoluble compounds which precipitate out of the water, thus reducing its availability.

DIP occurs in low concentrations and makes up a few percent of total phosphorus. The ratio of DIP to other forms is less than *ca* 5% and is fairly constant in surface waters within the temperate zone (**Wetzel 1983**). Orthophosphate is the most directly used form of both DIP and TDP. It reacts readily with acidic molybdate, which on reduction produces a coloured phosphomolybdenum blue species. Measured in this manner it is termed soluble reactive phosphorus (SRP). A preliminary digestion process is needed in order to convert the various TDP species to detectable orthophosphate.

A major component of the phosphorus cycle in natural waters is the exchange between sediments and the overlying waters. The effectiveness of the net movement of phosphorus to sediments and regeneration to the water depends on physical, chemical and metabolic processes. The most important factors are:

i) ability of sediments to retain phosphorus

ii) conditions of the overlying water

iii) presence of biota in the water which alter exchange equilibrium and which therefore promote phosphorus transport back to the water column.

Movement of phosphorus from sediment to interstitial water can be accelerated both by the action of biota and by turbulence. Exchange between the various forms of phosphorus may be rapid and involve numerous pathways. Organic phosphorus exists in two major fractions, a particulate form which is rapidly cycled and exchanged with soluble types and a dissolved form which is released and cycled more slowly.

6.1.2 Nitrogen

Nitrogen is also a major nutrient which affects the productivity of fresh waters. In unproductive oligotrophic lakes phosphorus availability is often the main factor that limits plant growth. If the water body experiences increased phosphorus loading, it is then possible for nitrogen to become more important as a growth-limiting nutrient **(Deevey 1970)**.

Nitrogen occurs in numerous forms, for example dissolved N_2, organic compounds such as amino acids, amines and proteins; inorganic forms such as ammonium (NH_4^+), nitrite (NO_2^+) and nitrate (NO_3^-). Sources include precipitation and particulate fallout whose output is variable and which depends on meteorological conditions and the location of waters relative to agricultural and industrial sources. No direct relationship exists between volume of rainfall and the quantity of nitrogen influx to an area **(Wetzel 1983)**. Dry fallout may contain ten times the quantity of nutrients as rainfall **(Wetzel 1983)**. Other sources include input from surface and groundwater, in addition to bacterial nitrogen fixation both in water and sediments.

Dissolved N	Particulate N
Organic: amino acids/amines/proteins	Organic: sewage/agricultural sources
Inorganic: ammonia/nitrite/nitrate	Inorganic: agricultural/industrial sources

Table 6.2: Speciation of nitrogen

Losses of inorganic and organic dissolved and particulate nitrogen to surface waters occur via outflow from the catchment. Further losses occur by reduction of NO_3^- to N_2 by bacterial denitrification, volatilization of NH_4^+ at high pH and permanent loss to sediments in the form of compounds containing inorganic and organic nitrogen.

In surface waters NH_4^+ concentrations may range from 0 to 5 mg l^{-1}. In well-oxygenated locations this form occurs only in low amounts. It is rapidly assimilated by algae and is the most significant source of nitrogen for plankton in many lakes. Concentrations of NO_2^- in natural waters are generally low, in the range 0 to 0.01 mg l^{-1}. Values increase under reducing conditions and are higher in streams that receive large amounts of organic matter. The range of NO_3^- is highly variable both seasonally and spatially. Sewage effluent inputs of nitrogen are often highly pulsed and nitrogen fertilisers may be applied seasonally to the land. The concentration of NO_3^- may vary from undetectable to 10 mg l^{-1} in eutrophic waters. The ratio of NO_3^- to NH_4^+ is also variable and depends on the relative contribution of natural and polluting sources of both forms of nitrogen. In calcareous regions the ratio may be 25:1 whereas in lakes which receive slight to moderate sewage effluent or agricultural applications of nitrogen fertilisers, it may be 1:10 (**Wetzel 1983**).

Dissolved organic nitrogen (DON), accounts for more than half of total dissolved nitrogen in surface waters and occurs in forms resistant to bacterial degradation. This fraction is 5 to 10 times greater than particulate organic nitrogen but the ratios between the two decrease in eutrophic lakes.

In studies of Lake Wingra, Wisconsin, USA **Isirimah *et al.* (1976)** found that 50% of available nitrogen in the water column existed in dissolved form, 20% in macrophytes and 30% in the interstitial water of sediments. Rapid turnover of NH_4^+ occurred in the water but not in the sediments, whereas for NO_3^- turnover was greater in the sediments and 80% was dinitrified to N_2.

6.2 Methods

Surface water samples were collected twice a month from sites A, B, BX, C, D and E (refer to **Chapter 5**, Field Sampling Sites and **Figure 4.2**) from February 1994 to December 1996.

		Streamflow m^3d^{-1}	Effluent flow m^3d^{-1}	SRP mgl^{-1}	TON mgl^{-1}	K mgl^{-1}	Piezometers mgl^{-1}
October 1991 to February 1992	Number of samples	5	5	35	35	-	-
	Sampling frequency	Monthly				-	-
	Source of data	Houston*	NRA	Houston*			-
July to December 1992	Number of samples	12	12	24	24	-	-
	Sampling frequency	Twice monthly				-	-
	Source of data	Author	NRA	Author			-
March to December 1994	Number of samples	20	20	60	60	60	-
	Sampling frequency	Twice monthly					-
	Source of data	Author	NRA	Author			-
March to December 1995	Number of samples	20	20	60	60	60	-
	Sampling frequency	Twice monthly					-
	Source of data	Author	NRA	Author			-
March to December 1996	Number of samples	20	20	60	60	60	100
	Sampling frequency	Twice monthly					
	Source of data	Author	EA	Author			

Table 6.3: Sampling frequencies for all parameters and source of data

Houston*: data from Houston (1992) is included to provide data for SRP and TON loadings to South Milton Ley before STW was extended

Subsurface water was taken from Plots Three and Six in 1996 and from all plots in August 1995 during reed fieldwork (**Table 6.3**).

During May 1996 the Technicon Autoanalyser used for determining TON and SRP was withdrawn from service because the tracking channels which record the results of analysis were not functioning. The Autoanalyser was not available for use again until March 1997. Samples taken during June – December 1996 were filtered and frozen until the Autoanalyser was repaired. Samples of known concentrations of TON and SRP were also frozen at the same time in order to determine any percentage change. The accuracy of the autoanalyser before and after repair was to 0.02 parts per million at low range (0 – 2 ppm) and 1 part per million at high range (0 – 20 ppm).

Water samples were collected following the guidelines given in the General Principles of Sampling (HMSO 1980). Screw-cap polyethylene sample bottles and glass-ware to be used in the laboratory were soaked in 10% hydrochloric acid for 48 hours in order to eliminate bacterial growth. This equipment was then rinsed with distilled-deionised water before use. Two sets of samples were collected at each site and *in situ* measurements of pH and conductivity readings were taken in order to record physico-chemical conditions.

The samples were transported to the laboratory within two hours to limit deterioration and were filtered through a Millipore filtration unit using GFC filters. They were then divided into three fractions for analysis of:

i) total dissolved nitrogen and phosphorus (TDP,TDN);

ii) inorganic nitrogen and phosphorus species (TON, SRP);

iii) total dissolved potassium (K).

In order to determine total oxidised nitrogen (TON) and soluble reactive phosphorus (SRP) a Technicon AutoAnalyser 11 was used. The calibration range for TON was 0-20 ppm and for SRP 0-2 and 0-20 ppm. If analysis was not possible directly after filtration, the sample was acidified to pH 2 using concentrated hydrochloric acid (0.5ml) and stored in the dark at 4^{o} C. The samples were then buffered and diluted before analysis by the Autoanalyser.

Total dissolved nitrogen and total dissolved phosphorus analysis was carried out according to the method developed by **Ebina *et al.* (1983)** and **Johnes and Heathwaite (1992)**. This involves the oxidation of nitrogen and phosphorus compounds present in each sample by digestion with a solution of potasium persulphate (20 g) and sodium hydroxide (3 g) dissolved and diluted to 1 litre in distilled-deionised water. The samples were then stored overnight at 4° C in the dark. Ten ml of persulphate solution and 10ml of sample were then put into a glass autoclave phial and autoclaved at 120° C for one hour. When cool the samples were analysed for the products of oxidation which were TON and SRP using a Technicon AutoAnalyser 11. In order to account for the dilution during autoclaving (1:2), TDP and TDN concentrations were multiplied by a factor of two.

Filtered water samples were analysed for potassium using a flame photometer. This was calibrated using 0-10 ppm standards of potassium chloride solution. After determination of samples the calibration was again checked. Accuracy is 2% linearity measured at mid-range when standardised at 3 ppm concentration. Precision is 1% variation for 20 consecutive readings.

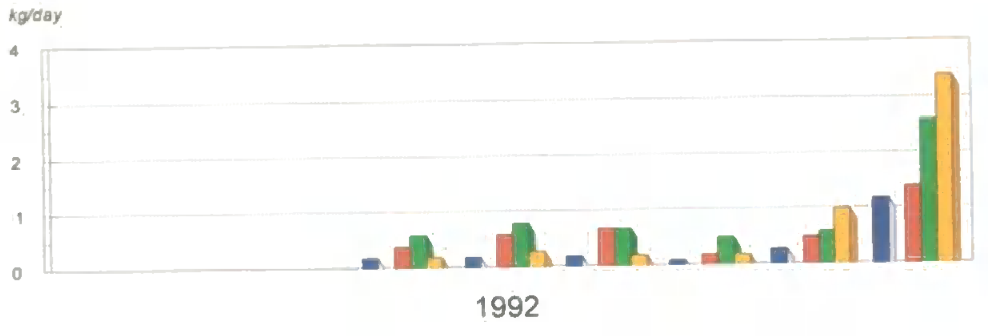
6.3 Results

6.3.1 Phosphorus: SRP

6.3.1.1 Data for 1992 (after sewage treatment works extension)

SRP loadings to the Ley from Site A, (diffuse; **Figure 6.1**) range from 0.1 to 1.2 kg d^{-1} with a mean for six months of 0.4 kg d^{-1} ± 0.4 SD. Loads have been calculated by multiplying concentration by stream flow – for example Site A, October: 0.1 mg $litre^{-1}$ x 1,416 m^3 d^{-1} /1,000 = 0.1 kg d^{-1}. There was little variation in the load of this determinand at Site A until November and December when there was a substantial increase. On all occasions except November concentrations of SRP at Site A were lower than those from point source, site BX, (sewage treatment works outlet, **Figure 4.2**). Loads have been calculated by multiplying concentration by stream flow and dividing the result by one thousand to give kg d^{-1}.

SRP



	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
A				0.2	0.2	0.2	0.1	0.3	1.2
BX				0.4	0.6	0.7	0.2	0.5	1.4
C				0.6	0.8	0.7	0.5	0.6	2.6
E				0.2	0.3	0.2	0.2	1.0	3.4

Figure 6.1

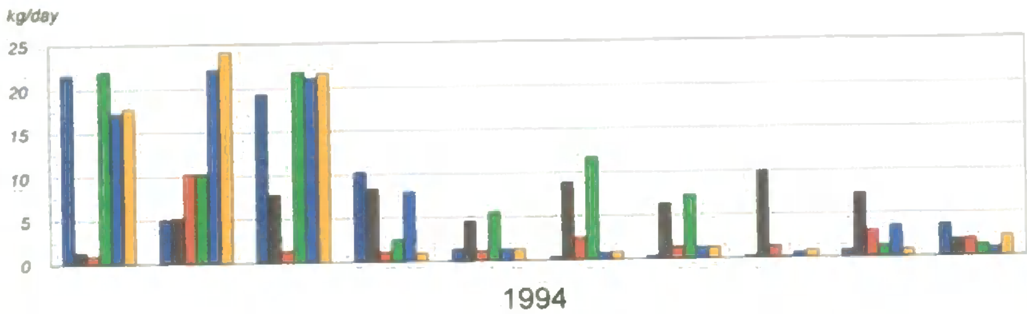
Loadings from point source, Site BX, contributed the greatest proportion of SRP to South Milton Ley and range from 0.2 to 1.3 kg d^{-1}. Levels increased until August when the highest value (1.3 kg d^{-1}) occurred. They then declined until a peak, 1.4 kg d^{-1} took place in December. Fluxes of SRP were low at site E. However there was a notable increase on the same two occasions as at Site A, (November and December) when values recorded exceeded levels found at Site BX.

Between 85 to 90% of orthophosphate entering South Milton Ley during 1992 came from the point source (Site BX) in August and 31 to 68% in November and December. This indicates that overall the point source substantially exceeded diffuse sources during summer. However the difference declines later in the year. SRP, TDP, TON, TDN and K data were not collected during 1993.

6.3.1.2 Data for 1994

During February to July 1994 **(Figure 6.2)** SRP loads at Site A were higher than at Site BX. From August to December (with the exception of October), values were greater at Site BX. **Figure 6.1** indicates that during 1992, the highest flux of SRP at Site A (1.2 kg d^{-1}) occurred in December. When this value is compared with the autumn of 1994 **(Figure 6.2)** a peak of 3.7 kg d^{-1} is indicated for October. The highest reading for Site BX in 1992 (1.3 kg d^{-1}) was recorded during August and for 1994 between July and December was 3.1 kg d^{-1} in November.

SRP



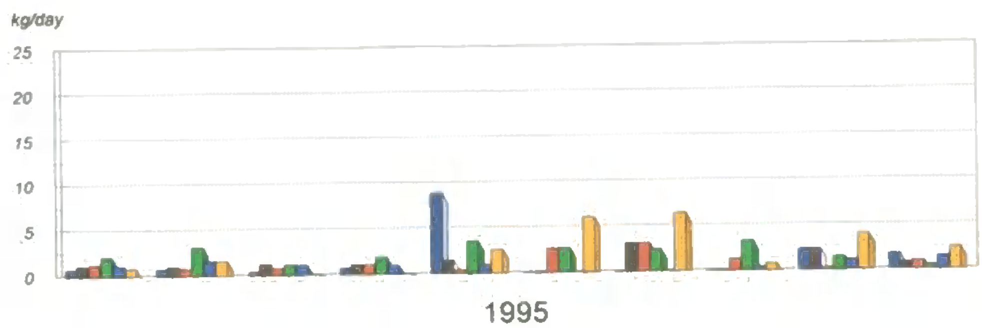
	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
A	21.6	5.2	19.4	10.4	1.4	0.4	0.4	0.3	1.0	3.7
B	1.4	5.3	7.8	8.5	4.6	8.9	6.4	10.0	7.3	2.0
BX	1.1	10.3	1.4	1.2	1.2	2.6	1.5	1.4	3.1	2.1
C	22.0	10.3	21.9	2.6	5.6	11.7	7.4	0.2	1.3	1.5
D	17.2	22.1	21.1	8.0	1.3	0.8	1.3	0.7	3.6	1.1
E	17.8	24.2	21.6	1.1	1.4	0.9	1.3	1.0	1.0	2.3

Figure 6.2

6.3.1.3 Data for 1995

The overall values for all sites during 1995 **(Figure 6.3)** were lower than those of 1994. The highest figure for Site A was 9.0 kg d^{-1} during July for Site BX, 3.2 kg d^{-1} in September. At the

SRP



	March	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
A	0.8	0.8	0.4	0.8	9.0	0.1	0.2	0.2	2.4	1.8
B	1.2	1.0	1.3	1.1	1.5	0.2	3.2	0.2	2.4	0.8
BX	1.3	0.8	0.8	1.1	0.4	2.7	3.2	1.4	0.3	1.0
C	2.1	3.2	1.1	2.0	3.6	2.7	2.5	3.3	1.5	0.6
D	1.2	1.6	1.1	1.0	1.0	0.1	0.2	0.4	1.2	1.5
E	0.9	1.6	0.2	0.2	2.8	6.1	6.5	0.8	4.1	2.5

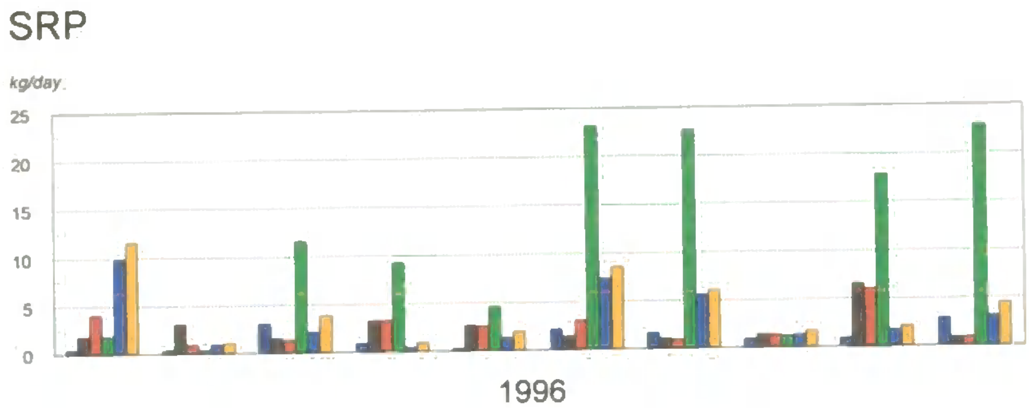
Figure 6.3

beginning and end of 1995 a greater amount of SRP was leaving the Ley at Site E than entering at Site A. From May to July there was a net gain to the system. In 1994 there was an overall loss of

SRP from the Ley at the latter end of the year and during 1993 there was a net export of SRP from the Ley from July to December.

6.3.1.4 Data For 1996

Values of SRP **(Figure 6.4)** recorded from July to December 1996 at Sites A, B, BX, and E were of a similar range to those observed in 1994 and 1995. Fluxes at Site E exceeded those at Site A on all occasions except during June. This indicated a net loss from the Ley.



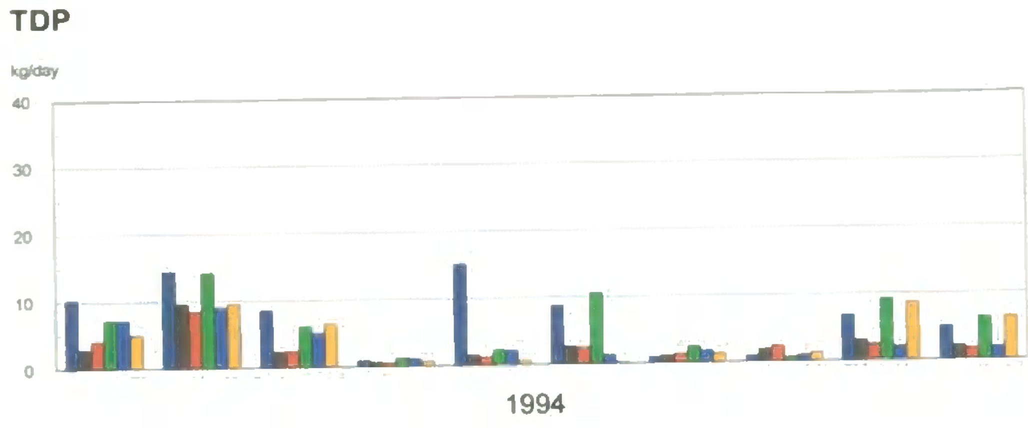
	Mar	April	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
A	0.5	0.4	3.0	1.0	0.3	2.3	1.7	1.0	1.0	2.9
B	1.9	3.0	1.5	3.3	2.7	1.4	1.1	1.3	6.5	1.0
BX	4.1	1.0	1.3	3.3	2.6	3.0	1.0	1.3	6.0	1.0
C	1.9	0.4	11.6	9.3	4.7	23.2	22.7	1.2	17.9	23.0
D	9.8	1.0	2.1	0.5	1.3	7.4	5.6	1.3	1.8	3.2
E	11.6	1.1	3.9	1.0	2.0	8.6	6.1	1.8	2.1	4.5

Figure 6.4

6.3.2 TDP

6.3.2.1 Data for 1994

Figure 6.5 shows that the highest values for TDP loads were found during February and April 1994 (data for 1992 and 1993 were not determined). TDP was highest at Site BX in April of that year, declined until June and then increased. Fluxes were greater from diffuse sources (Site A) than from point source (Site BX) except during November and December. There was a net gain of TDP to the system during 1994 for all months except November and December.

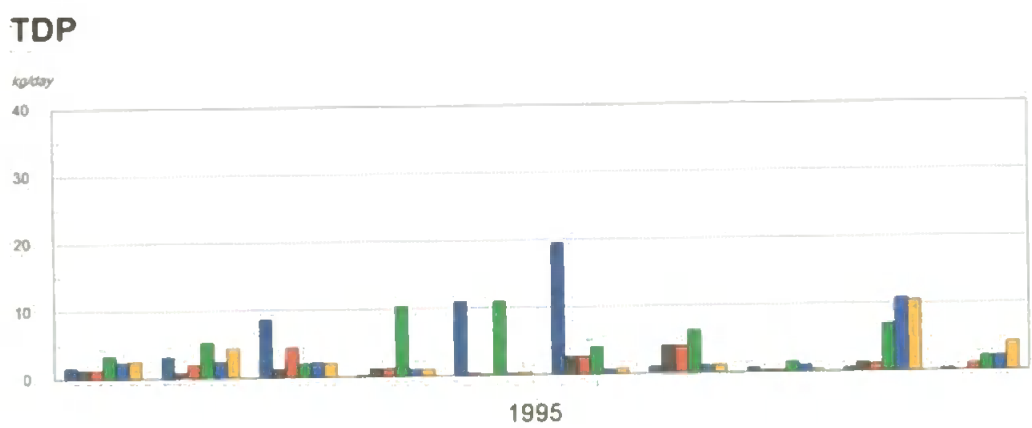


	Mar	April	May	June	Ju	Aug	Sep	Oct	Nov	Dec
A	10.3	14.5	8.6	1.0	15.2	8.8	1.0	1.0	6.8	5.1
B	2.9	9.7	2.4	0.7	1.6	2.7	1.2	1.9	3.1	2.1
BX	4.1	8.5	2.5	0.6	1.3	2.5	1.4	2.4	2.5	1.7
C	7.3	14.2	6.1	1.3	2.3	10.6	2.5	0.7	9.3	6.4
D	7.3	9.1	5.1	1.2	2.2	1.4	1.8	1.0	2.1	1.9
E	5.1	9.7	6.5	0.8	0.7	0.3	1.4	1.4	8.7	6.4

Figure 6.5

6.3.2.2 Data for 1995

During 1995 **(Figure 6.6)** TDP load was higher at Site BX than at Site A at the end of the year. More TDP was leaving the Ley than entering during March, April, November and December.

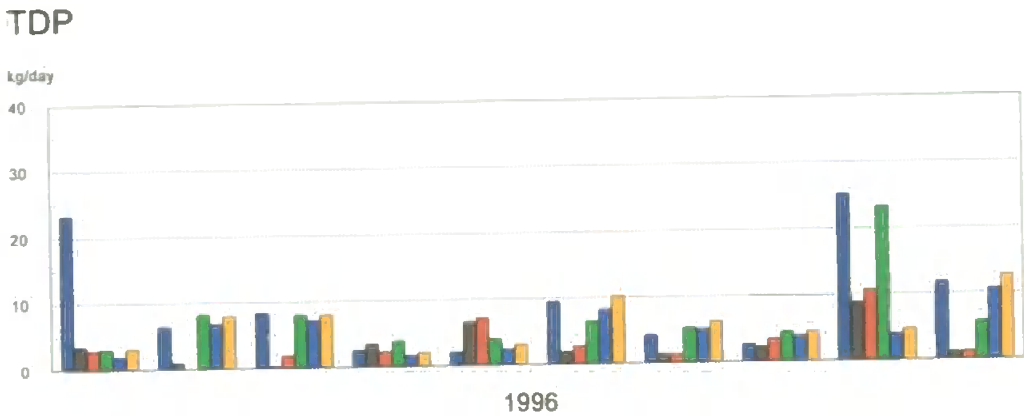


	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
A	1.7	3.2	8.6	0.3	11.0	19.6	1.0	0.8	0.6	0.4
B	1.4	0.9	1.2	1.2	0.4	2.7	4.2	0.3	1.3	0.2
BX	1.4	2.1	4.4	1.2	0.2	2.7	4.1	0.4	1.1	1.0
C	3.4	5.3	2.1	10.4	11.0	4.1	6.5	1.5	7.0	2.2
D	2.5	2.5	2.2	1.0	0.3	0.7	1.1	1.0	10.8	2.2
E	2.6	4.5	2.1	1.0	0.5	0.9	1.2	0.5	10.5	4.3

Figure 6.6

6.3.2.3 Data for 1996

Throughout 1996 **(Figure 6.7)**, except for July, all loads at Site A were higher than those at Site BX .The highest TDP fluxes for all sites were recorded during November 1996. The highest values recorded for Site BX was 8.5 kg d^{-1} in April 1994 **(Figure 6.5)**, 4.4 kg d^{-1} in May 1995 **(Figure 6.6)** and 10.7 kg d^{-1} in November 1996 **(Figure 6.7)**.



	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
A	23.3	6.5	8.4	2.6	2.2	9.6	4.3	2.7	25.2	11.9
B	3.5	1.0	0.3	3.5	6.7	2.0	1.4	2.3	8.8	1.2
BX	2.9	0.1	2.0	2.3	7.3	2.8	1.4	3.5	10.7	1.3
C	3.1	8.2	8.0	3.9	4.1	6.5	5.3	4.6	23.3	5.8
D	2.0	6.9	7.2	1.8	2.5	8.3	5.1	3.9	4.1	10.7
E	3.1	8.0	8.0	2.2	3.1	10.3	6.3	4.6	4.8	12.9

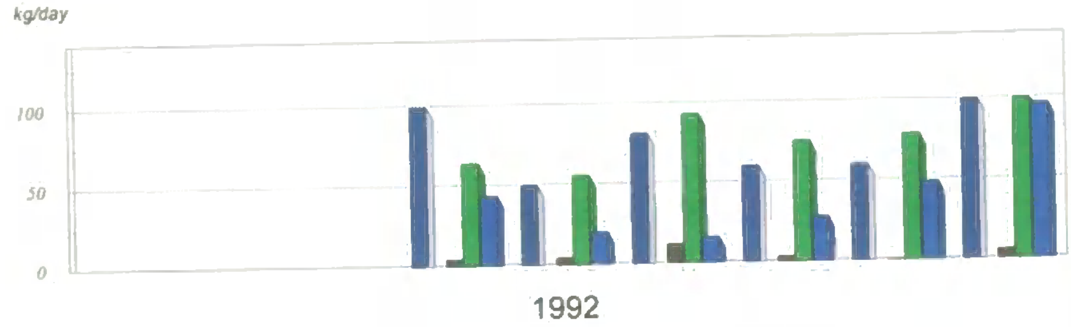
Figure 6.7

6.3.3 Nitrogen: TON

6.3.3.1 Data for 1992 – 1996

The highest reading of 100 kg d^{-1} **(Figure 6.8)** occurred in December and July, although peaks can also be identified for September, October and November. The lowest values that were recorded over the study period occurred at site BX (point source); the peak results measured at this site were in September and December. Results at site E range from 7.9 to 97.5 kg d^{-1} and in common with site A, the highest readings occurred in November and December. Diffuse fluxes were consistently greater than point sources. Except for September (87%), all readings indicated diffuse sources accounting for over 92% of TON loading to the Ley.

TON

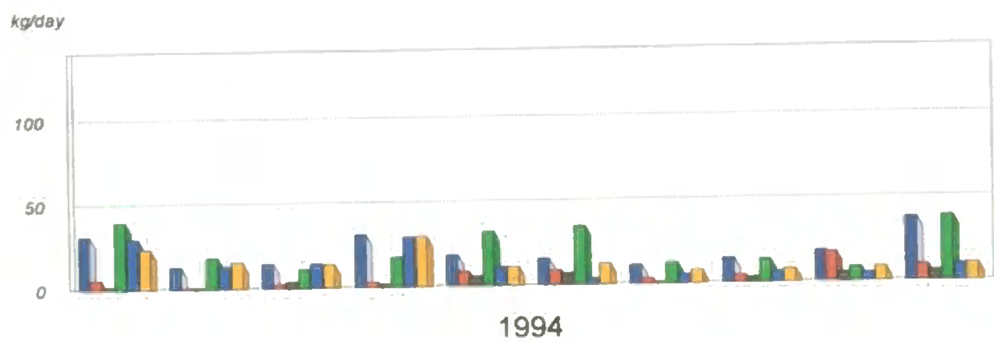


	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
A				100.0	50.1	81.5	60.6	60.6	100.0
B									
BX				4.7	5.0	12.3	3.7	1.2	6.0
C				64.2	56.5	93.3	75.3	79.4	100.0
E				44.5	20.4	16.8	28.6	49.8	97.5

Figure 6.8

Throughout 1992 **(Figure 6.8)**, 1994 **(Figure 6.9)** and 1996 (except March) **(Figure 6.11)** greater load of TON was recorded at Site A than Site E.

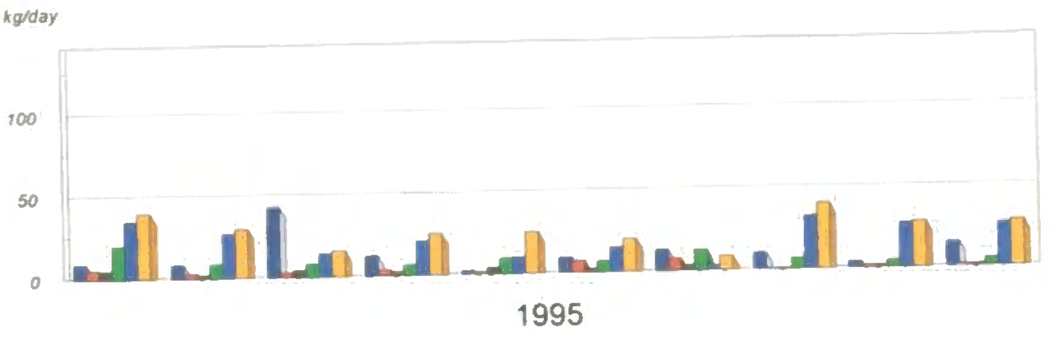
TON



	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
A	32.0	13.8	15.1	31.4	19.0	16.3	11.8	15.3	18.7	38.6
B	6.4	1.4	3.2	3.8	9.7	9.8	3.5	5.3	18.4	10.1
BX	2.0	1.5	4.2	2.5	6.4	7.8	1.9	3.5	5.5	6.6
C	40.0	19.2	11.8	18.6	32.7	34.7	13.3	14.6	8.8	38.8
D	30.2	13.7	15.1	30.4	11.4	4.6	5.5	7.1	5.9	10.3
E	24.0	16.2	14.0	30.4	11.8	12.8	8.2	8.1	8.8	10.8

Figure 6.9

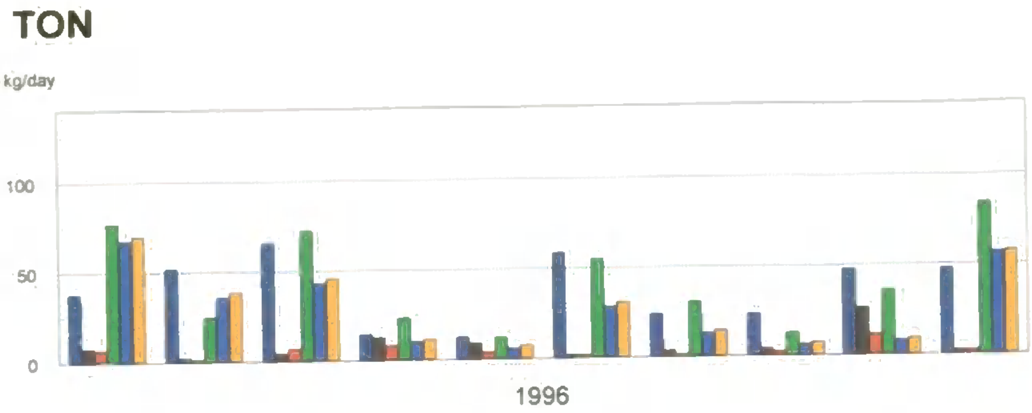
TON



	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
A	9.5	9.1	43.2	12.4	2.3	9.8	13.4	10.4	3.6	15.0
B	6.0	3.5	3.5	3.9	1.5	7.6	7.3	1.0	1.5	1.8
BX	5.4	2.5	4.3	2.8	3.9	2.8	3.3	1.0	2.1	1.5
C	20.0	9.0	7.9	6.5	9.8	6.6	12.3	6.5	4.9	5.4
D	35.2	27.1	14.3	21.3	10.3	15.4	3.0	32.5	27.6	26.4
E	40.0	30.0	16.2	25.0	25.0	20.0	9.0	40.0	28.0	28.0

Figure 6.10

This means that there was a net gain to the system. All readings display higher TON values at the diffuse source (Site A) than point source (Site BX). The values observed during 1992 were more like those of 1996, whereas loads recorded in 1994 were similar to those of 1995. The highest values for all sites were recorded during 1992 **(Figure 6.8)**.



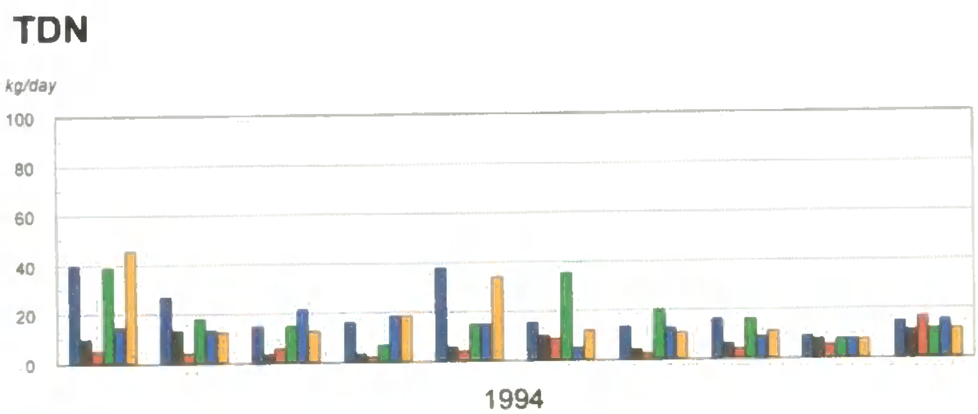
	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
A	38.0	51.8	65.9	14.5	12.5	58.7	23.8	23.4	48.0	48.0
B	7.9	2.8	4.4	13.0	9.0	2.0	3.5	4.5	26.5	2.4
BX	6.7	1.4	6.7	8.4	4.1	2.0	1.5	2.5	11.6	2.7
C	77.1	25.0	72.6	23.6	12.3	55.2	30.6	12.8	35.9	84.6
D	67.5	35.9	43.5	10.4	6.2	28.4	13.4	6.4	8.3	56.7
E	69.9	38.9	45.9	11.5	7.9	31.0	14.5	7.6	9.5	57.6

Figure 6.11

6.3.4 TDN

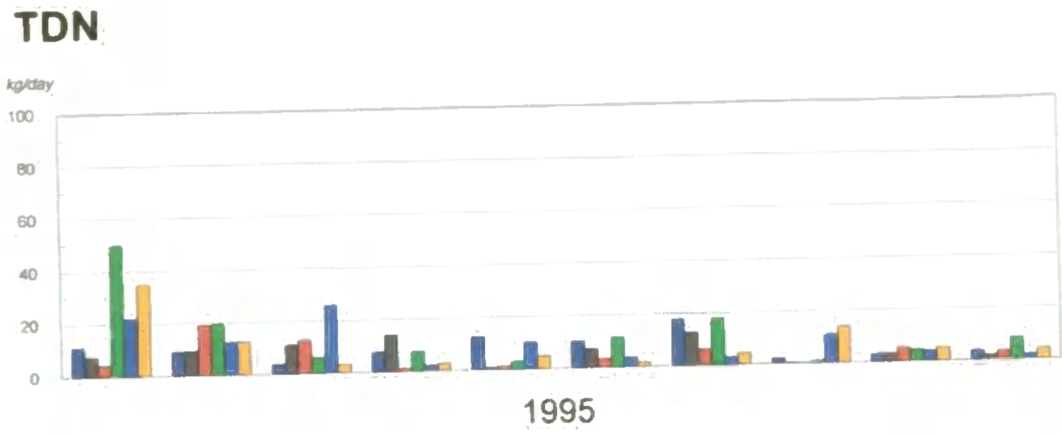
6.3.4.1 Data for 1994-1996

Figures 6.12 to **6.14** display TDN results over the period 1994 to 1996. The highest values occurred during 1996 **(Figure 6.14)** and the lowest during 1995 **(Figure 6.13)**. There was a net gain of TDN to the system during 1994 and 1996. Site A (diffuse source) accounted for a larger input of TDN to the system than Site BX (point source) during these years.



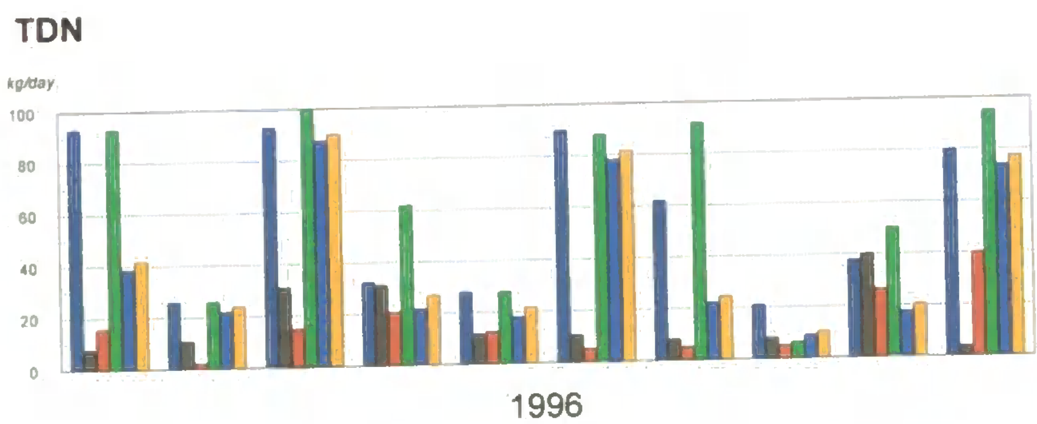
	Mar	April	May	June	Jul	Aug	Sep	Oct	Nov	Dec
A	40.0	27.1	15.1	16.5	38.0	15.5	13.6	16.3	9.3	14.9
B	10.0	13.5	3.4	3.6	6.0	10.3	4.5	6.3	8.0	11.4
BX	5.0	4.5	5.8	2.1	4.5	8.8	2.5	4.4	5.5	16.9
C	39.0	18.1	15.1	6.9	15.2	35.4	20.5	16.3	7.9	11.8
D	14.6	13.6	21.6	18.6	15.2	5.2	13.0	9.2	7.9	15.4
E	45.5	12.4	12.9	18.6	34.2	12.0	10.9	11.2	7.5	11.8

Figure 6.12



	Mar	April	May	June	Jul	Aug	Sep	Oct	Nov	Dec
A	11.5	9.1	3.9	7.7	12.9	10.3	17.9	2.4	3.2	3.9
B	7.4	9.5	11.2	14.0	1.2	7.2	12.8	0.7	3.2	2.1
BX	4.6	19.3	12.9	1.4	1.5	3.3	6.4	0.4	5.6	3.4
C	50.0	19.6	6.4	7.7	3.1	11.6	17.9	1.2	4.7	8.4
D	22.1	12.5	25.9	2.3	10.3	3.8	3.0	10.8	4.2	2.2
E	35.0	12.8	3.4	3.1	5.1	1.8	4.5	14.1	5.2	4.3

Figure 6.13



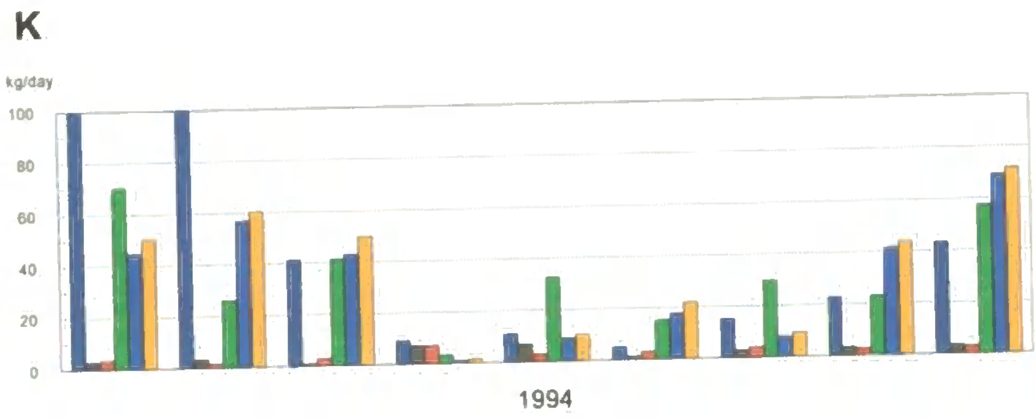
	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
A	93.0	25.9	93.0	32.4	28.0	90.0	62.1	21.0	38.0	80.0
B	7.9	10.8	30.8	30.8	11.7	10.8	8.2	8.3	40.1	4.0
BX	15.8	2.2	14.8	20.8	12.6	5.1	5.1	5.1	26.5	40.0
C	93.0	25.9	100.0	62.0	28.0	88.0	92.0	6.4	50.1	95.0
D	38.9	22.0	87.6	21.9	18.0	78.5	22.4	9.1	17.9	74.0
E	41.9	24.1	90.0	26.9	21.8	82.0	24.5	10.5	20.7	77.6

Figure 6.14

6.3.5 Potassium

6.3.5.1 Data for 1994

In 1994 **(Figure 6.15)** the greatest loading of potassium to the Ley took place during April to June. Values then declined until a further rise in November and December. The highest value (100 kg d^{-1}) for Site A occurred in April and May and the lowest (1.2 kg d^{-1}) was recorded at site B in June.



	April	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
A	100.0	100.0	41.5	9.5	11.3	5.3	15.4	22.9	43.7
B	3.0	3.7	1.2	7.2	6.9	1.7	3.0	3.7	3.9
BX	3.8	1.8	3.2	7.2	3.1	3.2	4.2	3.2	3.4
C	70.5	26.3	41.5	3.6	32.9	15.5	30.1	23.5	57.9
D	45.0	57.1	43.5	1.4	9.3	18.0	8.1	41.6	69.3
E	50.7	60.5	50.1	1.9	10.5	22.2	9.8	44.1	72.0

Figure 6.15

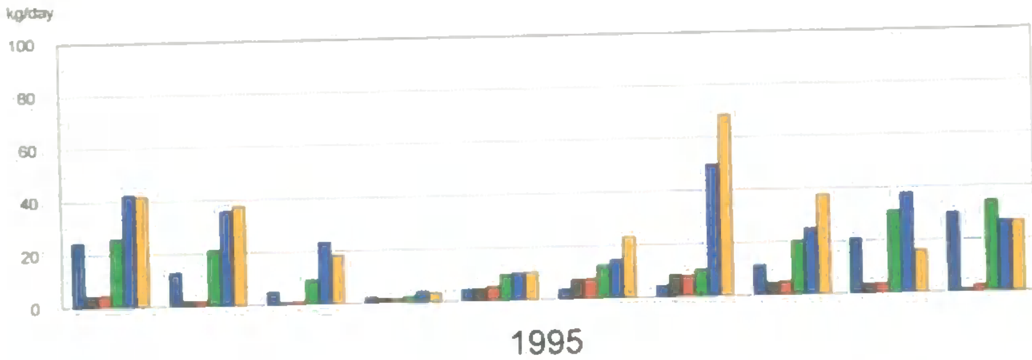
6.3.5.2 Data for 1995

Figure 6.16 indicates that loads at Site BX (point source) exceeded those from Site A (diffuse source) during July, August and September of 1995. Values of potassium during this year were lower than in 1994 and 1996.The highest load (68.6 kg d^{-1}) was recorded at Site E in September and the lowest (10 kg d^{-1}) at Site B in May.

6.3.5.3 Data for 1996

The highest reading (93.8 kg d^{-1}) for 1996 **(Figure 6.17)** was recorded in December at Site A and the lowest, (1.0 kg d^{-1}) in April and May at sites B and BX. Except for June, fluxes for Site A exceeded those for Site BX.

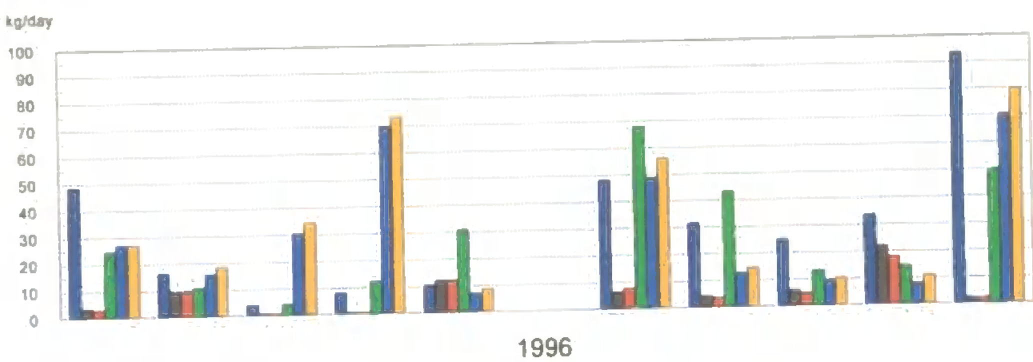
K



	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
A	24.6	13.1	5.1	2.3	4.5	3.8	4.6	11.5	21.1	30.3
B	4.5	2.2	1.0	2.0	4.9	7.5	8.5	4.7	3.7	1.3
BX	4.5	2.2	1.2	1.6	5.6	7.7	8.3	5.2	3.8	2.7
C	26.2	21.3	9.5	2.3	9.8	12.5	10.4	20.5	31.2	34.6
D	42.5	38.0	23.8	4.2	10.6	14.8	50.0	25.2	38.0	28.8
E	41.8	37.7	18.5	3.7	10.6	23.3	68.6	37.8	16.2	26.8

Figure 6.16

K



	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
A	48.9	16.5	4.3	8.2	10.5		48.3	31.8	25.2	33.9	93.8
B	3.7	9.6	1.0	1.0	12.0		6.3	4.2	5.8	22.1	2.3
BX	3.1	9.6	1.0	1.0	12.0		7.7	3.8	4.9	18.0	2.1
C	24.8	10.7	4.3	12.3	31.0		68.3	43.4	13.3	14.5	50.0
D	27.2	16.0	30.5	70.0	7.1		49.0	12.9	9.4	8.0	70.6
E	27.2	18.6	34.5	73.8	8.8		56.2	14.8	10.5	10.8	80.0

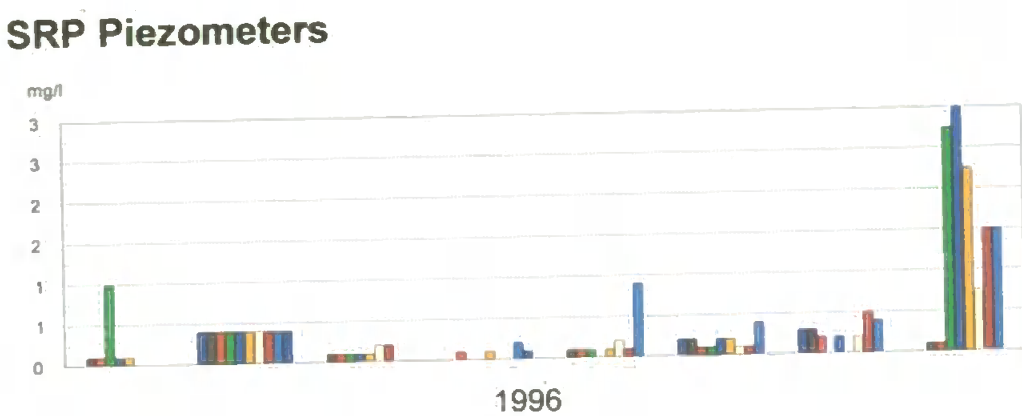
Figure 6.17

6.3.6 Transect piezometers

Refer to **Figure 4.2** for location of piezometers.

6.3.6.1 Data for SRP 1996

Figure 6.18 displays concentrations for SRP from March to December 1996. Blank results indicate dry piezometers. The greatest concentration of this determinand (3.0 mg l^{-1}) was found in December in Transect Three, Plot Three. This high value may be due to seepage from South Milton Stream where high SRP loadings were recorded at Site C 23 kg d^{-1} (**Figure 6.4**). The lowest values and the least number of results were recorded during July. The range of values and results for all of the piezometers was uniform during April.



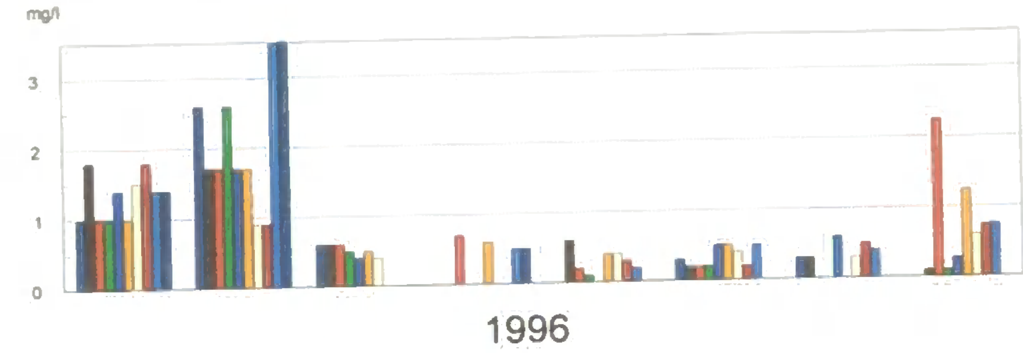
	Mar	April	May	June	Aug	Oct	Nov	Dec
T1 PL6	0.1	0.4	0.1		0.1	0.2	0.3	0.1
T2 PL3	0.1	0.4	0.1	0.1	0.1	0.1	0.2	0.1
T2 PL6	1.0	0.4	0.1		0.1	0.1		2.8
T3 PL3	0.1	0.4	0.1			0.2	0.2	3.0
T3 PL6	0.1	0.4	0.1	0.1	0.1	0.2		2.3
T4 PL3		0.4	0.2		0.2	0.1	0.2	0.8
T4 PL6		0	0		0	0	1	2
T8 PL3		0.4		0.2	0.9	0.4	0.4	1.5
T8 PL6		0.4		0.1				

Figure 6.18

6.3.6.2 Data for TDP 1996

The highest concentration of TDP and the most complete set of results were in March and April, **(Figure 6.19).** The highest values (3.3 mg l^{-1}), **(Figure 6.19)**, were recorded during April in Transect Six, Plots Three and Six. The fewest results were recorded in June and the lowest in Transect Two, Plot Six (0.1 mg l^{-1}) during August.

TDP Piezometers



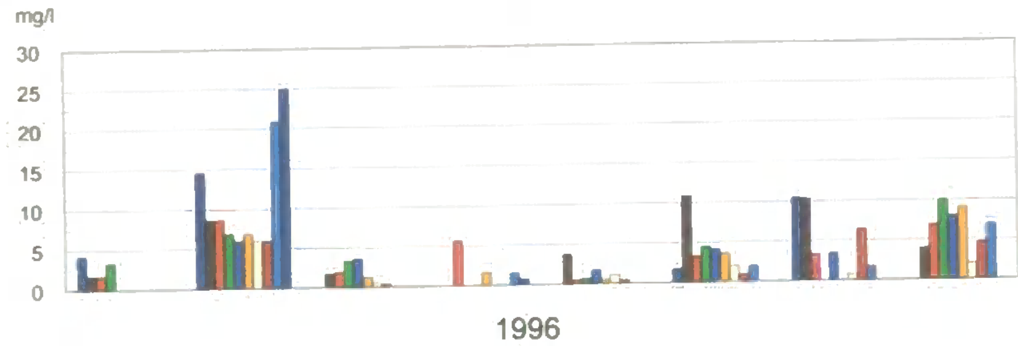
	Mar	April	May	Jun	Aug	Oct	Nov	Dec
T1 PL3	1.0	2.6	0.6			0.3	0.3	
T1 PL6	1.8	1.7	0.6		0.6	0.2	0.3	0.1
T2 PL3	1.0	1.7	0.6	0.7	0.2	0.2		2.3
T2 PL6	1.0	2.6	0.5		0.1	0.2		0.1
T3 PL3	1.4	1.7	0.4			0.5	0.6	0.3
T3 PL6	1.0	1.7	0.5	0.6	0.4	0.5		1.3
T4 PL3	1.5	0.9	0.4		0.4	0.4	0.3	0.6
T4 PL6	1.8	0.9			0.3	0.2	0.5	0.8
T6 PL3	1.4	3.5		0.5	0.2	0.5	0.4	0.8
T6 PL6	1.4	3.5		0.5				

Figure 6.19

6.3.6.3 Data for TON 1996

The highest concentrations and most complete results for TON **(Figure 6.20)** occurred during April. Transect Six, Plots Three and Six produced values of 20 mg l^{-1} and 25 mg l^{-1}. The lowest concentrations occurred in August, Transect Two and Four and the least number of results was recorded in June.

TON Piezometers



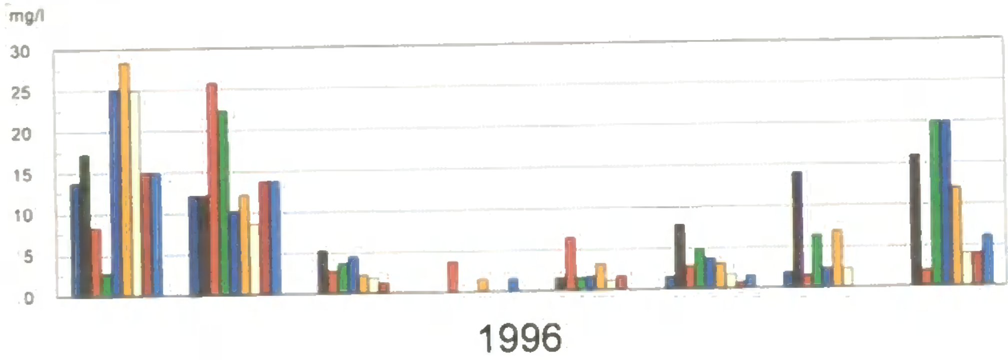
	Mar	April	May	Jun	Aug	Oct	Nov	Dec
T1 PL6	1.8	8.6	1.8		3.8	10.9	10.3	4.0
T2 PL3	1.8	8.6	1.9	5.7	0.6	3.3	3.4	7.0
T2 PL6	3.4	6.9	3.4		0.7	4.5		10.0
T3 PL3		6.0	3.6		1.8	4.2	3.5	8.0
T3 PL6		6.9	1.3	1.6	0.6	3.6		9.0
T4 PL3		6.0	0.6		1.1	2.0	0.8	2.0
T4 PL6		6.0	0.4		0.5	1.0	6.5	4.8
T6 PL3		20.9		1.5		2.0	1.8	7.0
T6 PL6		25.0		0.8				

Figure 6.20

6.3.6.4 Data for TDN 1996

The highest concentrations of TDN were recorded during March, April and December, **(Figure 6.21)**. During these months the high values occurred in: Transects Three and Four in March (28.5 mg l^{-1}), Transect Two in April (25.9 mg l^{-1}) and Transects Two and Three in December (20.0 mg l^{-1}). Lowest concentrations and fewest results were recorded in June, (1.5 mgl^{-1}, Transect Six) and August (1.4 mg l^{-1} Transect Four).

TDN Piezometer

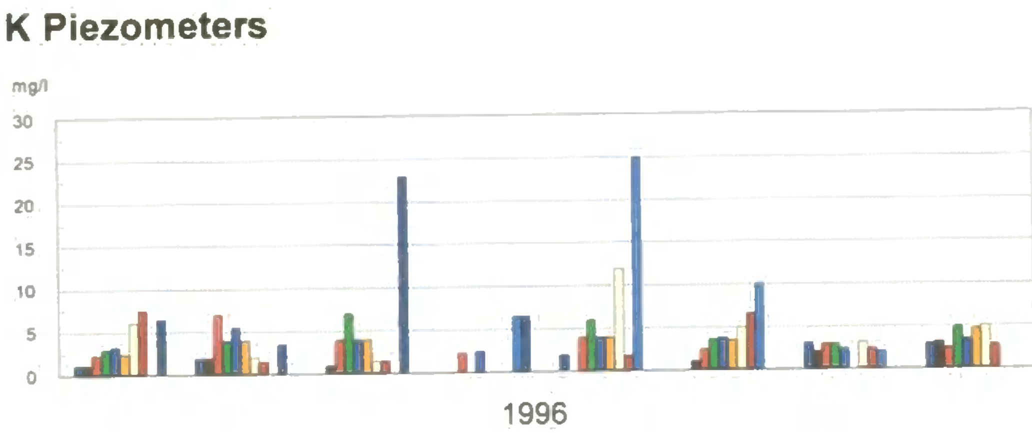


	Mar	April	May	Jun	Aug	Oct	Nov	Dec
T1 PL3	13.8	12.1				1.6	1.9	
T1 PL6	17.3	12.1	5.3		1.6	7.8	14.[illegible]	16.0
T2 PL3	8.3	25.9	2.8	3.7	6.4	2.8	1.5	2.0
T2 PL6	2.8	22.5	3.8		1.6	4.8	6.4	20.0
T3 PL3	25.2	10.3	4.6		1.7	3.7	2.4	20.0
T3 PL6	28.5	12.1	2.2	1.6	3.2	3.0	6.8	12.0
T4 PL3	25.0	8.6	1.8		1.2	1.7	2.3	4.0
T4 PL6	15.0	13.8	1.3		1.7	0.8		4.0
T6 PL3	15.0	13.8		1.5		1.5		6.0

Figure 6.21

6.3.6.5 Data for K 1996

Figure 6.22 indicates that potassium concentrations were highest during August (Transect Six, 25.0 mg l^{-1}). Transect Four produced the highest values (3.0 mg l^{-1}) over the study period and Transect One the lowest (1.0 mg l^{-1}). Fewest values were recorded during June.



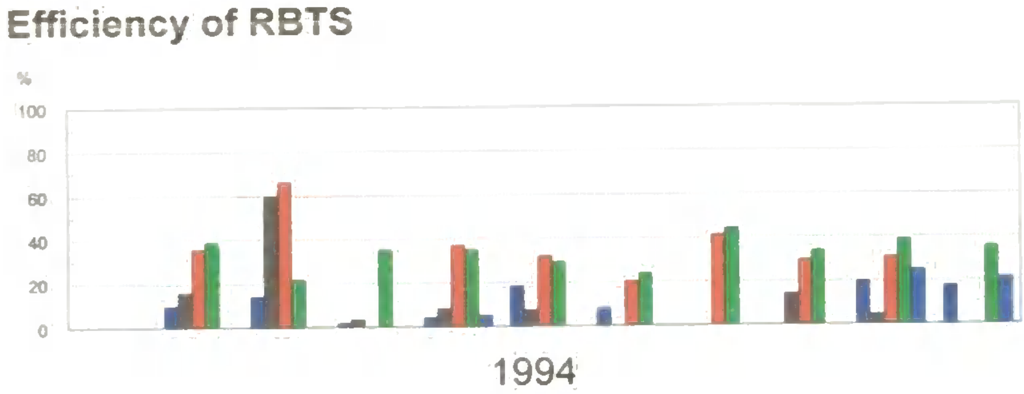
	Mar	April	May	Jun	Aug	Oct.	Nov	Dec
T1 PL3	1.1	2.0			2.0		3.1	3.0
T1 PL6	1.1	2.0	1.0		0.0	1.2	2.1	3.1
T2 PL3	2.3	7.0	4.0	2.4	4.0	2.5	3.0	2.5
T2 PL6	3.0	4.0	7.0		6.0	3.7	3.0	4.9
T3 PL3	3.3	5.5	4.0	2.5	4.0	3.8	2.5	3.5
T3 PL6	2.5	4.0	4.0	0.0	4.0	3.5		4.7
T4 PL3	6.1	2.0	1.4		12.0	5.0	3.1	5.0
T4 PL6	7.5	1.5	1.6		1.8	6.6	2.5	2.9
T6 PL3				6.5	25.0	10.1	2.1	
T6 PL6	6.5	3.5	23.0	6.5				

Figure 6.22

6.4 Efficiency of RBTS

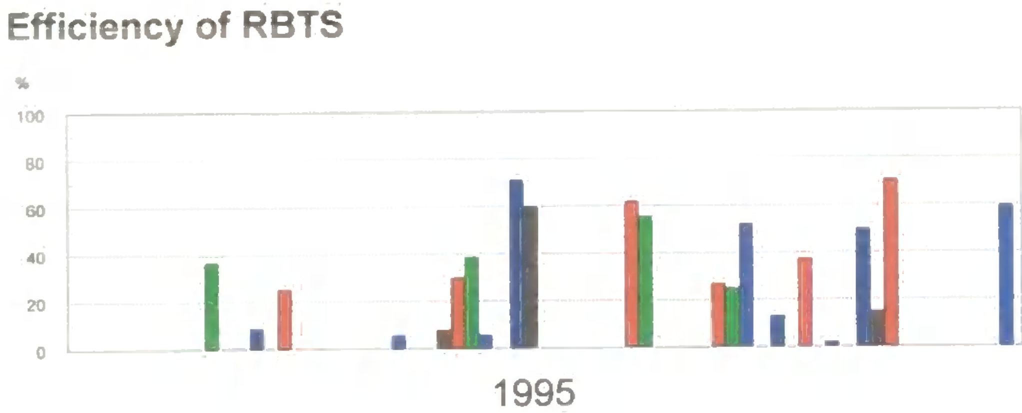
6.4.1.1 Data for 1994

Figure 6.23 to 6.25 display the efficiency of the RBTS at South Milton Ley for removing TDP, SRP, TDN, TON and K for 1994 – 1996. The efficiencies were calculated twice weekly from values measured at Site B (effluent entering the RBTS) and Site BX (effluent leaving the RBTS). Effluent flow was monitored by the EA (see p 41). Blank values indicate that a greater amount of determinand was leaving the RBTS than entering. During 1994 **(Figure 6.23)**, the greatest removal efficiency was for TDN and TON with a range of 20.6% to 66.3%. Potassium removal efficiency results were the poorest with only three months indicating positive values (June, 5.5%, November 25%, and December 21.2%). The highest readings for all determinands occurred during April and December and the lowest during February. A peak value of 60% removal efficiency of SRP was recorded in April. TDP results were lower than those for SRP until July and from August to December removal efficiency for this determinand increased. The flow of effluent was monitored by the EA (refer to p. 41).



	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
TDP	0.0	10.0	14.2	2.2	4.6	18.8	8.3	0.0	0.0	19.8	18.0
SRP	0.0	16.0	60.0	4.0	8.4	7.7	0.0	0.0	14.5	4.7	0.0
TDN	0.0	36.0	66.3	0.0	37.2	32.0	20.6	41.3	29.7	30.9	0.0
TON	0.0	39.0	22.0	35.2	35.2	29.6	23.8	44.4	34.0	39.1	35.6
K	0.0	0.0	0.0	0.0	5.5	0.0	0.0	0.0	0.0	25.0	21.2

Figure 6.23



	Feb	Mar	April	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
SRP	0.0	0.0	9.1	0.0	0.0	71.4	0.0	0.0	13.2	50.0	0.0
TDP	0.0	0.0	0.0	0.0	8.0	60.0	0.0	0.0	0.0	15.0	0.0
TON	0.0	0.0	25.2	0.0	30.0	0.0	62.0	27.2	37.5	70.8	0.0
TDN	0.0	36.6	0.0	0.0	39.0	0.0	55.8	25.0	0.0	0.0	0.0
K	0.0	0.0	0.0	5.8	5.8	0.0	0.0	52.3	2.3	0.0	59.6

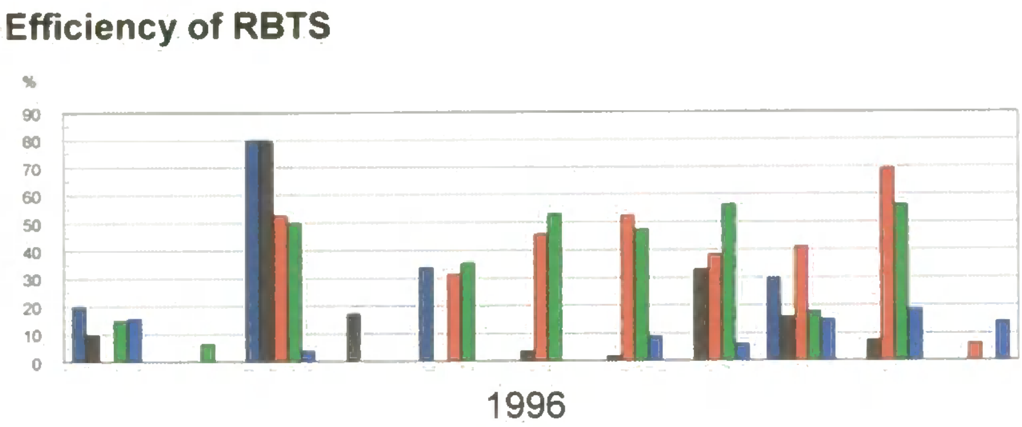
Figure 6.24

6.4.1.2 Data for 1995

During February, March, May and December 1995, the RBTS did not remove any TDP, SRP or TON (**Figure 6.24**). Apart from SRP for July (71.4%) and TON for November (70.8%) the removal efficiencies of the RBTS were low compared to 1994 and 1996.

6.4.1.3 Data for 1996

For 1996 the RBTS was least efficient in March **(Figure 6.25)** whereas in April and October there was positive removal efficiency for all determinands. April also produced the highest removal (80%) for TDP and SRP. However there was poor TDP removal throughout the rest of the year with seven months showing none. The greatest removal efficiency throughout 1996 was for TON. The lowest annual range for 1996 (4.0% to 18.8%) were recorded for K. The number of months with positive removal efficiency were greater during 1996 than during 1994 or 1995.



	Feb	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
TDP	20.0	0.0	80.0	0.0	34.0	0.0	0.0	0.0	29.7	0.0	0.0
SRP	10.0	0.0	80.0	17.3	0.0	3.7	2.0	33.0	15.9	7.4	0.0
TDN	0.0	0.0	52.9	0.0	31.7	46.0	52.6	38.5	41.3	69.5	6.4
TON	15.0	6.6	50.0	0.0	35.3	53.4	47.5	56.5	17.8	56.3	0.0
K	15.7	0.0	4.0	0.0	0.0	0.0	9.0	6.0	15.0	18.8	14.2

Figure 6.25

6.5 Annual and mean daily SRP, TON and K loadings to South Milton Ley

Tables 6.4 to **6.6** display mean daily and annual loading to South Milton Ley for SRP, TON and K. Diffuse loads of TON and K are greater than those from point sources. Results for diffuse TON for 1993 were the highest and are almost double those for 1996. The highest mean daily streamflow (90.24 l sec^{-1}) occurred during 1994 and coincided with the highest flux of diffuse SRP **(Table 6.4)**.

The lowest mean daily point loading to the Ley was recorded in 1992 for SRP, 1995 for TON and

	SRP		Mean daily flow Litres/sec		TON		K	
	Point	Diffuse	Point	Diffuse	Point	Diffuse	Point	Diffuse
1992a	0.36	1.81	2.00	51.65	3.15	26.69	-	-
1992b	0.79	0.36	4.90	46.88	3.37	77.96	-	-
1994	2.67	5.40	4.20	90.24	4.19	25.40	3.32	37.94
1995	1.30	1.90	3.11	41.58	2.90	15.48	4.30	14.51
1996	2.00	1.40	5.11	80.89	4.80	44.00	6.32	38.60

Table 6.4: Mean daily SRP, TON & K loading (kg d^{-1}) to South Milton Ley from point and diffuse sources

1992a - data collected before STW extension (source Houston 1992)
1992b - data collected after STW extension (source Powell 1993)

in 1994 for K. There was an increase in loads for all determinands in 1996. Mean daily point flow readings were lowest in 1992 and highest in 1996.

	SRP		TON		K	
	Point	Diffuse	Point	Diffuse	Point	Diffuse
1992a	2.13	0.48	18.35	7.75	-	-
1992b	1.91	0.62	7.61	40.76	-	-
1994	5.65	1.14	18.80	14.16	12.43	4.80
1995	4.50	1.20	12.01	7.64	17.73	4.37
1996	4.10	0.20	11.00	11.00	10.60	7.50

Table 6.5: Mean daily SRP, TON & K concentration mg l^{-1}

1992a - data collected before STW extension (source Houston 1992)
1992b - data collected after STW extension (source Powell 1993)

Table 6.5 contains results of total annual loadings of SRP, TON and K. The highest results for SRP and K occurred in 1994 and those for TON were recorded in 1993. The annual load of SRP has increased by 100% between 1992 and 1996.

	SRP	TON	K
1992a	3.65	69.35	-
1992b	3.65	253.00	-
1994	16.70	63.53	97.30
1995	6.90	39.51	40.38
1996	8.10	104.80	96.40

Table 6.6: Total annual load g m^2 a^{-1}

1992a - data collected before STW extension (source Houston 1992)
1992b - data collected after STW extension (source Powell 1993)

6.6 Discussion

6.6.1 Nitrogen, Phosphorus and Potassium Inputs to South Milton Ley

The pattern of nutrient concentration along the Ley can be seen from **Figures 6.1 to 6.17**. Site A **(Figure 4.2)** represents the nutrient load from the catchment whereas Sites BX and C reflect the input of effluent from the STW. The variability of values at Site C indicates that sewage is poorly mixed with Ley water at this stage. At Site D concentrations are lower than at site BX (STW) probably owing to processes such as adsorbtion, precipitation, biological uptake and denitrification of the wetland. Site E is influenced by seawater, thus producing high potassium concentrations and variable results for nitrogen and phosphorus. The technique employed here for determining phosphorus tends to underestimate values in brackish and saline conditions by 1 mg l^{-1} so results for this determinand could be higher than shown **(Froelich & Pilson, 1978** and **Ridal & Moore, 1990)**.

The main source of SRP at South Milton Ley is from the sewage treatment works (point source, Site BX, **Table 6.5**). Input of this determinand is at its greatest during August when there is an increase in the local population from tourists.

It can be seen that throughout the summer for all years there is a net input to the system that suggests that storage is occurring. From August onwards there was a net export of this determinand from the Ley as plant uptake declines. Also phosphorus is probably leached into the water at this time owing to vegetation die-back. Therefore there is temporary storage of nutrients by vegetation during the growing season as assimilation occurs and release of nutrients in the winter. Further release of phosphorus into solution may occur if there is a disturbance of soils during storms. Mean annual SRP concentrations for 1994 and 1996 are higher than those for 1995. Higher rainfall during these years may have caused an increase in the concentration of this determinand, as reflected by peak values during the winter months. As rainfall interacts with soil, desorption, dissolution and mineralisation of phosphorus occurs which helps movement of dissolved phosphorus in runoff. Percolation of rain through the soil profile then transfers dissolved phosphorus to subsoils and subsurface flow. Movement of sediment phosphorus, which is comprised of particulate forms adsorbed by soil particles and organic matter is governed by erosion. Therefore phosphorus losses from cultivated land comprise 75% to 95% particulate fraction whereas runoff from grass and woodland contains largely dissolved phosphorus (**Wilson 1995**). The catchment of South Milton Ley is 65% grassland.

The main source of stream-borne nitrogen and potassium to the Ley is the catchment (as opposed to the sewage treatment works). Peak values from diffuse sources occur during high rainfall and high loads are sustained as water runoff from the catchment continues. In common with SRP, a net release of TON occurs during November and December when there would have been lower rates of de-nitrification within the Ley, and greater decomposition and leaching of nutrients into the surrounding water. Potassium values also reached high peaks at the beginning and the end of the year that indicate the effect of rainfall and seasonal vegetation die-back.

For 1994 – 1996 TON concentrations in the final effluent (Site BX) represent 79%, 60% and 32% of the total dissolved nitrogen. SRP fluxes for the same years represent 50%, 60% and 65% of the total dissolved phosphorus. **Finstein & Hunter (1967)** state that at least 50% of phosphorus in wastewater is hydrolysed to SRP during treatment. It would seem that over the three years 30 to 80% of all total dissolved nitrogen and 50 to 65% of total dissolved phosphorus was available for uptake by vegetation.

Seasonal changes in concentration of dissolved nutrients reflect the influence of hydrology. The input of diffuse sources of TON is affected by variations in inputs to the Ley from the catchment. During periods of high throughflow, the removal of this determinand by denitrification may be reduced owing to increased oxygen concentration in the water. The solubility or otherwise of phosphorus also depends on availability of oxygen (**Etherington 1983**). During floods the presence of deep water in the Ley creates conditions in which oxygen may become scarce. This may lead to phosphorus release from the sediments and an increase in concentration of orthophosphate. Therefore water depth, residence time and fluctuations in oxygen directly affect uptake and release both of nitrogen and of phosphorus.

6.6.2 Transect Wells

Concentrations of nitrogen, phosphorus and potassium in subsurface water recorded high values occurring in Transects Four and Six. These were measured at the beginning and end of the year during wetter months The results do not indicate the presence of 'edge effect' caused by runoff from the catchment and plots nearest to South Milton Stream produced increased concentrations of all determinands which may be caused by effluent mixing with Ley waters. All values for all determinands were lower than those measured in South Milton Stream but followed the same trend of increased concentrations during the winter months when lower temperatures slow down key chemical and biological processes.

6.6.3 Comparison With Other Data

Tables 6.4 - 6.6 compare phosphorus and nitrogen loading to South Milton Ley from 1992 – 1996. This includes data from **Houston (1992)**, a study that was carried out before the extension to South Milton sewage treatment works was in operation. Diffuse and point loads were determined over the period from October 1991 to February 1992. Also included and identified in the tables as (b) are data from **Powell 1992** from a study that was carried out during July – December 1992 after the STW extension was completed.

In comparison to this work the mean daily loading of TON from diffuse sources (**Table 6.4**) has increased with low values in 1992 and 1995. This could be because both these years experienced low rainfall thus reducing nutrient input from the catchment. The mean daily loading of TON from the point source (sewage effluent) has increased in 1996 as has the mean daily load of SRP which exhibits a rise of over 400% (0.36 kg d^{-1} to 2.0 kg d^{-1}). Poor RBTS performance and an increase in resident and tourist population served by the STW may account for this increase.

Residence times and phosphorus loads of South Milton Ley and Slapton Ley are set out in **Table 6.6** where the annual input of total phosphorus to South Milton Ley is the equivalent of 21.9 g m^{-2}

Houston (1992) which in areal terms is over three times as great as that of Slapton Ley (6.2 g m^{-2}) **Johnes and O'Sullivan (1989)**.

	Catchment area/volume	Residence time	Loading rate
South Milton	21.76	Max 11 days	21.9 g m^2a^{-1}
Slapton	35.9	Average 18 days	6.2 g m^2a^{-1}

Table 6.7: A comparison of residence times and loadings of total phosphorus, South Milton Ley and Slapton Ley

The maximum residence time (11 days) at South Milton Ley is just over half the mean residence time (18 days) of Slapton Ley. Therefore in comparison with Slapton Ley, the loading rate for South Milton Ley (when it is acting as a lake) is higher. The lower residence time may not be sufficient to compensate for this extra loading. At its present loading rate there is a great deal of evidence of eutrophication in the Lower Ley at Slapton **(O'Sullivan *et al.* 1989)**.

Havens *et al.* (2001) compared the nutrient dynamics of three lakes which were shallow (< 4 m mean depth), relatively large (> 30 km^2) and heavily influenced by human activity. In the Lake Okeechobee catchment, the major land use is animal agriculture and 40% of land is undeveloped. Urban areas use centralised sewage treatment and septic tanks. The total P loading to this lake is 0.24 g $m\text{-}^2$ a^{-1}. Lake Kasumigaura has a total P loading of 1.3 g $m\text{-}^2$ a^{-1}. Major land use in its catchment is crops, fruit growing and paddy fields. 12% of the land has urban, industrialised and residential uses. Agriculture accounts for 72% of the catchment of Lake Donghu and 28% is urban, industrial and residential. Untreated sewage waste from areas of Wahan city is discharged into the lake. Lake Donghu is classified as highly eutrophic according to the trophic classification of lakes included in **(Vollenweider 1975)** and has a total P loading of 3.2 g m^{-2} a^{-1}.

Although these lakes differ from South Milton Ley in size and nature of human influence, they share general properties of shallow lake nutrient dynamics. The comparison of their total P loadings with the figure of 21.76 g m^{-2} a^{-1} **(Table 6.7)** for South Milton Ley prior to the expansion of the sewage treatment works indicate that the Ley could be classed as hypereutrophic.

South Milton Ley does not show signs of eutrophication at present. However this cannot be taken to imply that the present loading at South Milton is acceptable; it may be that no eutrophication has yet been observed because physical conditions have so far prevented it. Breaching of the sand-bar at times of high levels of nutrients would cause these to be rapidly flushed from the system, and thereafter as long as the sand-bar stays open, the residence time will be low.

6.6.4 Efficiency of RBTS

The consent to discharge for the extended works was based on the performance of the previous works (**NRA (now EA) consent to discharge, Appendix 1**). Samples collected by **Houston 1992** showed a 95%ile phosphate discharge of 7.64 mg $sec^{-1.}$ Houston believed that the level of discharge from the previous works was established by the EA by estimation rather than measurement. This may account for the figure that they set for the 95%ile load for that STW (40 mg $s^{-1} \equiv 11$ mg l^{-1}) being so much in excess of concentrations measured in this study and in hers. If her supposition is correct, and given the stated objectives of the EA that the present loadings should not be exceeded, the consent level has been set too high. If it is not reviewed in this respect, the impact of this error may eventually become evident in the Ley.

The load limits for nitrate and ammonia set by the EA did not appear (in comparison with data from **Houston 1992**) to be in excess of those already received by the Ley. The results of this study show that the mean daily load of TON does not differ significantly from those obtained from the previous sewage treatment works by the EA or by **Houston (1992)**.

In order to maintain the throughput of N and P at the previous levels despite the increase in the volume of effluent processed, an artificial reedbed was incorporated into the new sewage treatment works at South Milton Ley (as mentioned in **Section 2.7**). **Spangler *et al.* (1978)**, states that the proportions of N and P that can be expected to be removed by a RBTS are in the range 5 to 25% for total P. For dissolved inorganic nitrogen, figures ranged from a reduction of 60% to an increase of 47%. **Coombes (1990)** states that in a study of reedbed treatment systems established by Anglian Water Services Limited, the efficiency of the RBTS as tertiary treatment did not improve significantly as the reedbed matured and that nitrification and phosphorus removal were poor.

Low RBTS efficiency results were recorded at South Milton Ley for TON (34% in 1994 to 20.9% in 1996) and for SRP (19% in 1994 to 9.3% in 1996). These may have resulted from an uneven flow of water through the bed and lack of maintenance of reed growth. During 1994-6 the RBTS was operating with less than a quarter of its total area planted with reeds and no harvesting was carried out (**Plate 6.1 and 6.2**).

From this study it can be seen that there has been an increased loading of SRP on the Ley whereas nitrogen loadings have reduced. Potassium concentrations show a great variability. During 1994 removal of this determinand by the RBTS occurred during only three months. In 1996 potassium removal efficiency was poorer but occurred during seven months of the study. The loading of phosphorus does give cause for concern. This nutrient is described as the main controller of plant growth and the effects of excess amounts on the ecology of the reedbed of South Milton Ley may not yet be apparent.

Plate 6.1: Uneven flow of effluent at outlet of reed bed treatment system

Plate 6.2: Poorly maintained reed bed treatment system

CHAPTER SEVEN

Study of *Phragmites australis*

7.1 Sampling Sites

Fieldwork on *P. australis* was carried out at the end of August in the years 1994 and 1995. During these years samples were collected at the time of maximum standing crop (equivalent to stage 10.5 in cereals). Characteristics of above-ground shoots were studied but rhizomes and roots were not considered owing to the difficulty of sampling sediment-rooted stands of reed (refer to **Chapter 5**, Field Sampling Sites).

7.2 Methods

Shoots and seed heads in each 1 m^2 plot **(Table 7.1)** were counted in order to determine density. The presence of other plant species was also noted. Ten randomly chosen shoots were then cut at ground level, placed in plastic bags in order to minimise dehydration and taken back to the laboratory. All shoot measurements were made on the day plants were collected from the field. Lengths were measured from leaf tip to 1 cm from the stem base and the number of internodes recorded. The diameter at the base of each stem was measured using vernier calipers. Shoots were cut and weighed to the nearest 0.01g to give fresh weight and then dried in ovens at 80° C for 36 hours. They were then reweighed in order to calculate biomass for each plot. Water levels were recorded at the time of sampling and water chemistry analysis (refer to **Chapter 6, Methods 6.2**) was carried out within a week of the vegetation sampling.

- Inland -

Distance from sewage treatment works	Transect	Plot 1	2	3	4	5	6
(-200m)	1	*	*	*	*	*	*
(-150m)	2	*	*	*	*	*	*
♣ STW							
(3m)	3	*	*	*	*	*	*
(400m)	4	*	*	*	*	*	*
(600m)	5	*	*	-	-	*	*
(800m)	6	*	*	-	-	*	*

- Sea -

♣ Location of sewage treatment works

* 10 reeds were sampled in each plot

\- No data (transect 5 and plot 4 were inaccessible in 1995 and could not be sampled

Variable name	Description
Transect	From 1 to 6 across the ley
Distance	Distance of transect from sewage treatment works (m)
Plot	From 1 to 6 per transect
Height	Reed height (cm)
Diameter	Basal diameter of reeds (mm)
Internode	Number of internodes
Biomass	Average dry weight per reed (g) times density per m^2 (gm^2)
Density	Number of shoots per plot

Table 7.1: Sampling sites and reed variables

7.2.1 Laboratory Work

To test the effect of different ratios of N:P:K on the growth of *P. australis*, plants were grown under laboratory conditions where external influences such as water level, light and nutrients could be controlled. This work was undertaken from April to December 1996.

Rhizomes were collected from South Milton Ley in April 1996. Four tanks were set up and ten rhizomes containing an apical bud grown in each. The growth medium consisted of Perlite and a 10 cm top layer of sand.

Considerable time was taken in order to determine the best way to provide a constant flow of solution through the tanks. The use of plastic piping, header tanks and gravity did not prove to be successful as the flow was difficult to adjust and monitor. Therefore it was decided to add one litre of solution manually to each of the four tanks three times a week. A hole was cut at the same height in each tank and a plastic pipe was used as an overflow. This enabled a constant level of water to be maintained. The tanks were placed under fluorescent lighting which was kept on for twelve hours and off for the same period each day. The growing room was maintained at a constant temperature of 15°C. The ratio of nutrient solutions supplied to each tank was as follows:

	N mg l^{-1}		P mg l^{-1}		K mg l^{-1}	
Tank 1	Low	5.0	High	5.0	Low	3.0
Tank 2	High	15.0	Low	1.0	Low	3.0
Tank 3	Low	3.0	Low	1.5	Low	3.0
Tank 4	High	15.0	High	4.0	Low	3.0

Table 7.2: Nutrient solutions

These concentrations represent the minimum and maximum ranges of N, P and K determined in subsurface and surface water at South Milton Ley. To each solution, 0.25g l^{-1} calcium sulphate, 0.5g l^{-1} magnesium sulphate and 0.02 g l^{-1} ferric EDTA was also added.

Each month measurements of length, diameter and number of internodes were recorded for every plant in the tanks. At the end of the experimental period the plants were cut, weighed and dried in order to calculate biomass for each tank.

7.3 Results

7.3.1 Fieldwork Data 1994

Results of the analysis of physical characteristics of reeds from South Milton Ley are presented in **Figures 7.1 - 7.6.** The diagrams indicate respectively that there are differences in reed height **(Fig 7.1)**, stem diameter **(Fig 7.2)**, number of internodes **(Fig 7.3)**, reed density **(Fig 7.4)**, biomass **(Fig 7.5)** and number of seedheads **(7.6)** between transects and between plots. In comparing reed characteristics above and below the outlet, it would be wrong to rely on a simple independent sample's t-test since the variation between transects and plots will inflate the standard error. A better test would be a non-parametric test which is a test of equality of medians rather than means but is used to test means if the distribution is symmetric and the assumption of the parametric t or f-tests are not met.

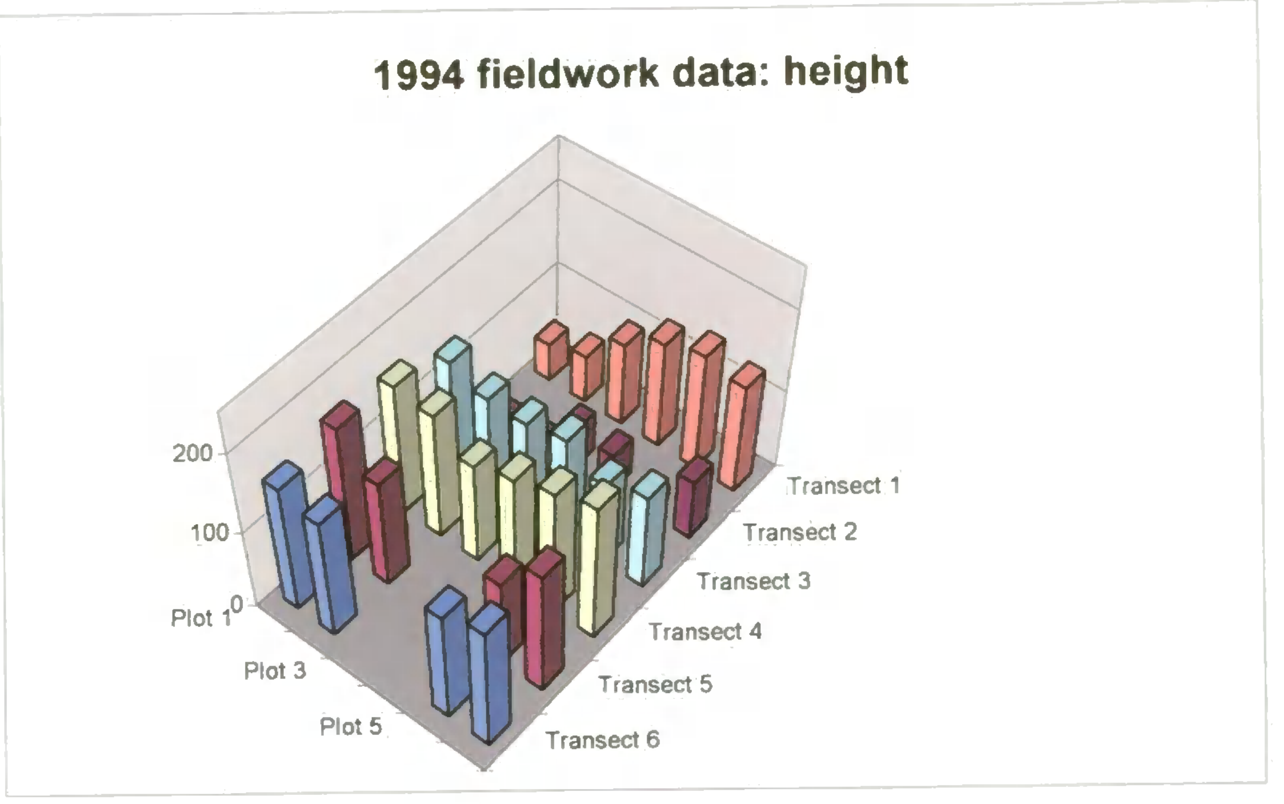
Reeds within a plot cannot be regarded as independent observations. Samples of 10 were taken from 'finite plot populations' ranging from 5 (when all 5 were taken) to 140. Hence the observations of the sample reeds will be correlated (**Manly 2001** and **Cox & Snell 1989**). A Mann-Witney test was therefore carried out to determine whether there were significant differences in reed growth above and below the STW.

The contrast compares the two transects above the STW with the four transects below. The results for height, diameter and biomass (**Figure 7.1, 7.2** and **7.5**) are very highly significant ($P < 0.001$). Therefore Transects Three to Six (below the STW) contained taller reeds with larger diameter and biomass than Transects One and Two above the outlet. The number of seedheads and internodes (**Figure 7.3** and **7.6**) were greater in transects below the STW ($P = 0.02$). There is no evidence to indicate density (**Figure 7.4**) was greater below the STW ($P > 0.05$).

7.3.2 Fieldwork Data 1995

Data from Transect five and Plot Four (every Transect) were not collected in 1995 owing to difficulty of access because of flooding. **Figures 7.7 - 7.12** represent the results of 1995 fieldwork data.

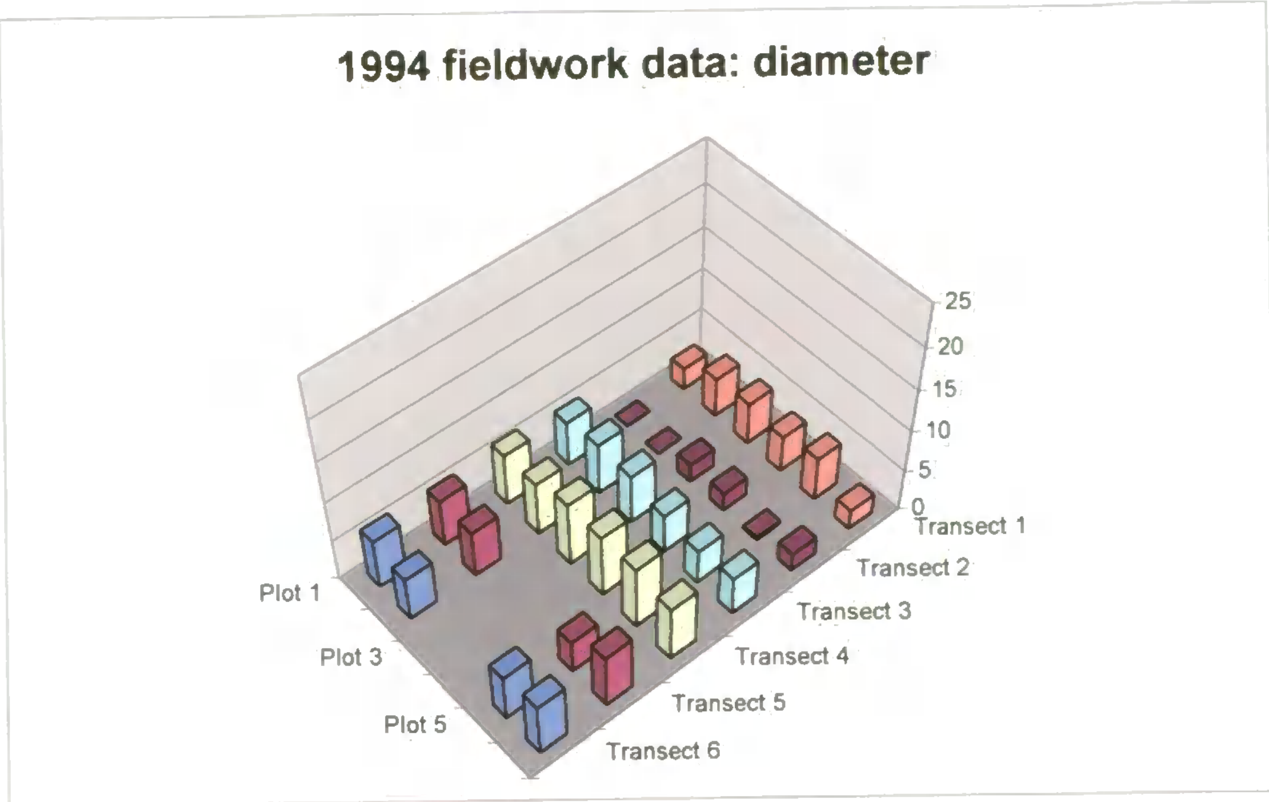
The results of the Mann-Witney test for reed growth during 1995 show that there is a lot of evidence ($P < 0.01$) to suggest that the number of seedheads was greater in Transects Three to Six (below the STW) than in Transects One and Two above. There is no evidence to indicate that height (**Figure 7.7**), diameter (**Figure 7.8**), internodes (**Figure 7.9**), density (**Figure 7.10**) and biomass (**Figure 7.11**) are higher below the STW ($P > 0.05$).



	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6
Transect 6	158.8	149.1			137.0	154.8
Transect 5	170.8	133.3			107.6	153.8
Transect 4	163.1	157.4	125.0	139.9	154.6	170.5
Transect 3	136.0	119.0	117.8	127.6	101.5	118.6
Transect 2	0.0	0.0	50.2	45.5	12.6	73.9
Transect 1	47.1	59.0	102.7	131.4	144.9	135.1

Mean reed height: cm n ≤ 10

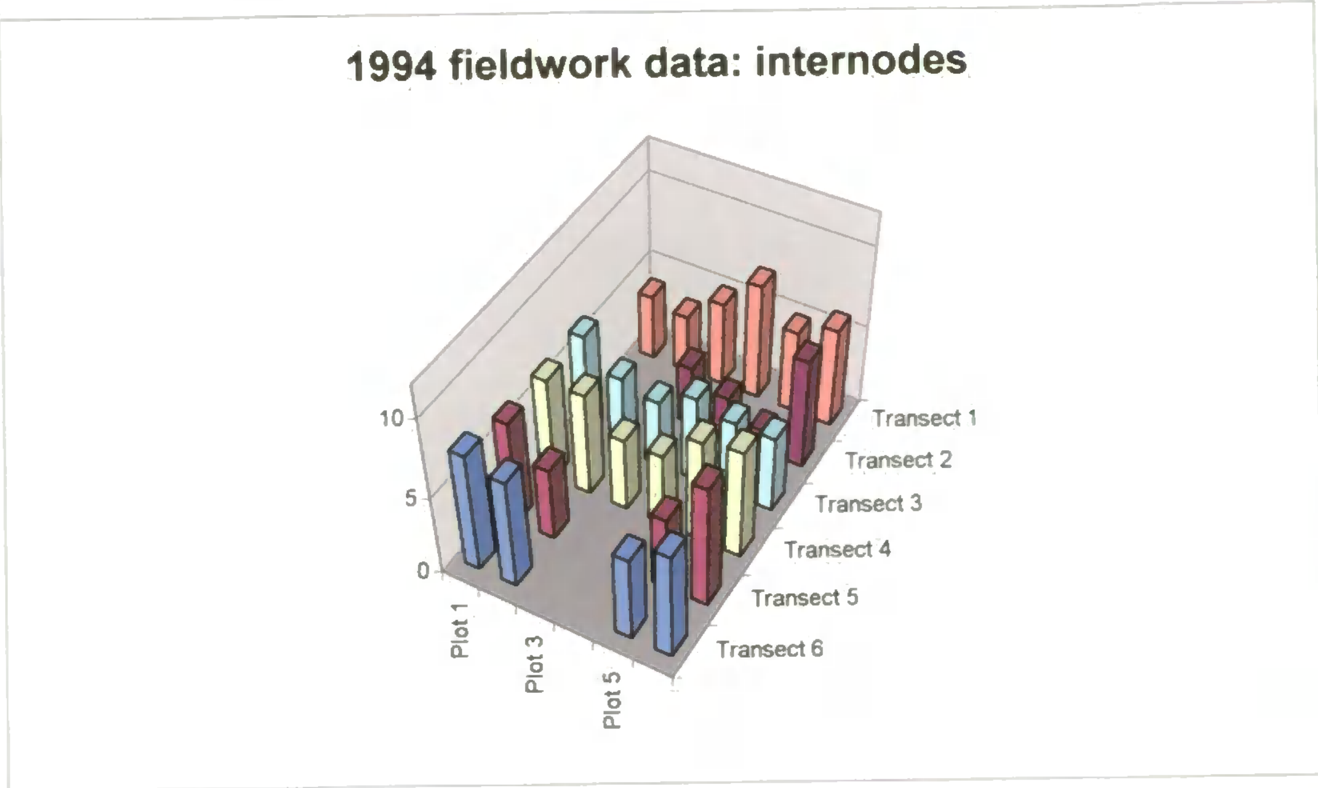
Figure 7.1 Reed height data from South Milton Ley, August 1994



	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6
Transect 6	6.0	5.2			5.5	6.3
Transect 5	5.7	5.6			3.9	6.4
Transect 4	6.3	6.4	7.7	7.5	7.5	6.6
Transect 3	5.4	6.2	5.9	4.7	4.1	4.6
Transect 2	0.0	0.0	2.2	2.2	0.3	2.1
Transect 1	2.6	4.7	5.0	4.3	5.2	2.3

Mean reed diameter: mm $n \leq 10$

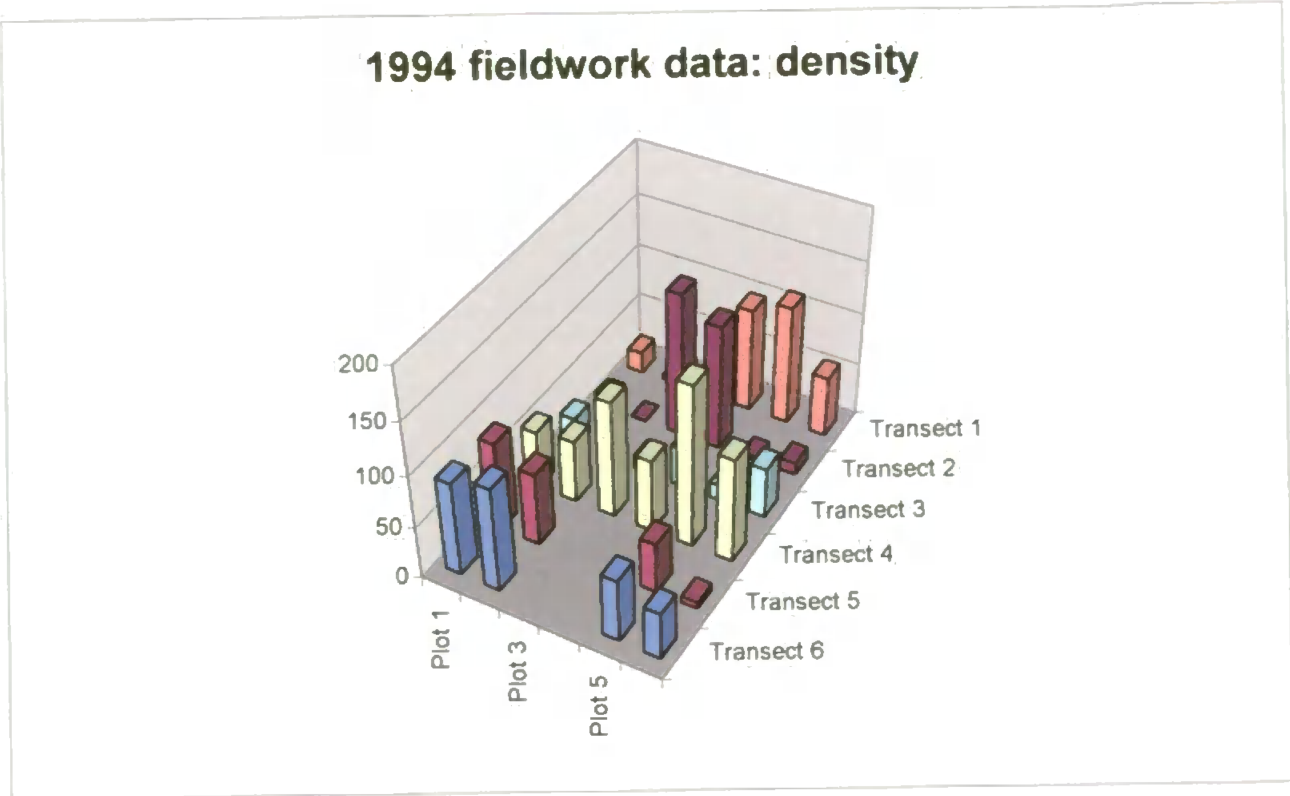
Figure 7.2 Reed diameter data from South Milton Ley, August 1994



	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6
Transect 6	7.5	6.9			5.3	6.7
Transect 5	6.6	4.6			4.6	7.7
Transect 4	6.5	6.5	4.6	4.6	6.5	6.9
Transect 3	6.6	4.8	4.2	5.4	4.8	4.8
Transect 2	0.0	0.0	3.7	2.6	1.4	6.9
Transect 1	4.1	3.6	5.3	7.3	5.2	6.2

Mean number of internodes: $n \leq 10$

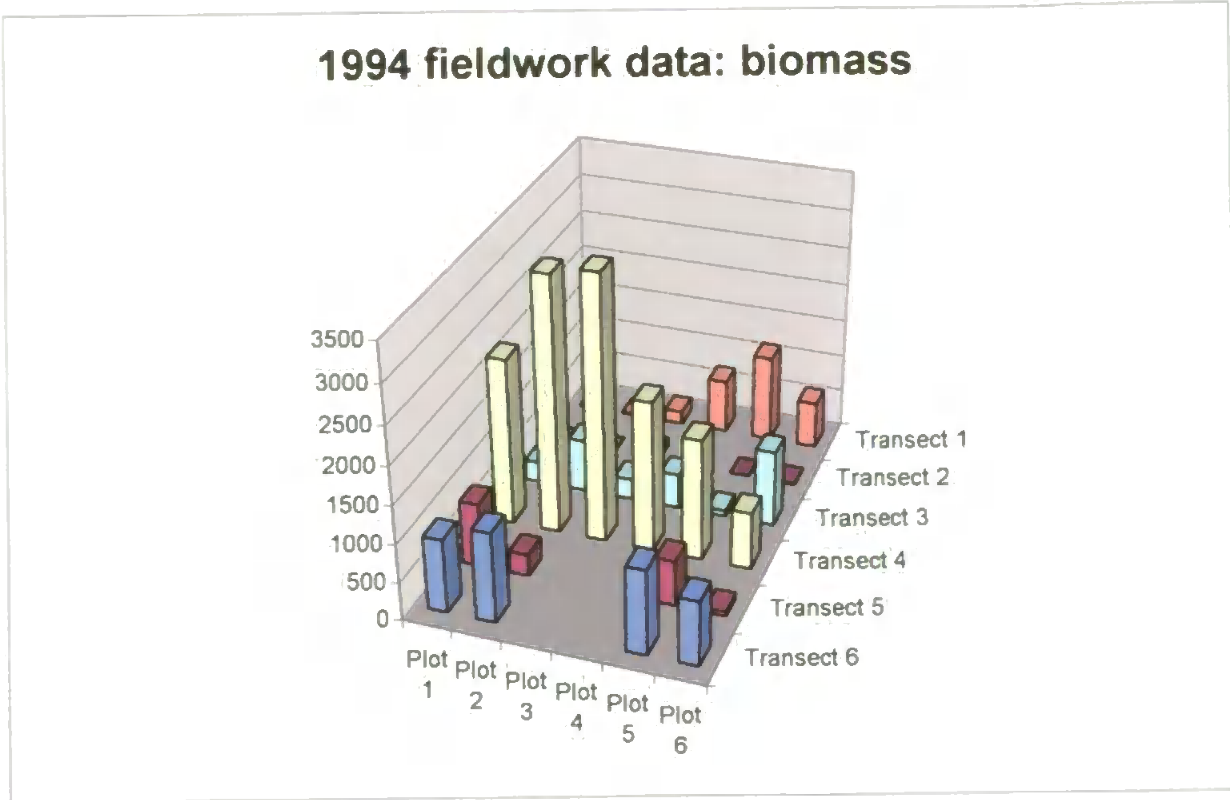
Figure 7.3 Reed internodes data from South Milton Ley, August 1994



	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6
Transect 6	90.0	100.0			60.0	45.0
Transect 5	85.0	70.0			48.0	6.0
Transect 4	55.0	60.0	112.0	70.0	155.0	100.0
Transect 3	28.0	63.0	13.0	38.0	15.0	48.0
Transect 2	0.0	0.0	139.0	120.0	3.0	12.0
Transect 1	20.0	5.0	23.0	100.0	114.0	58.0

Density: no. per square metre

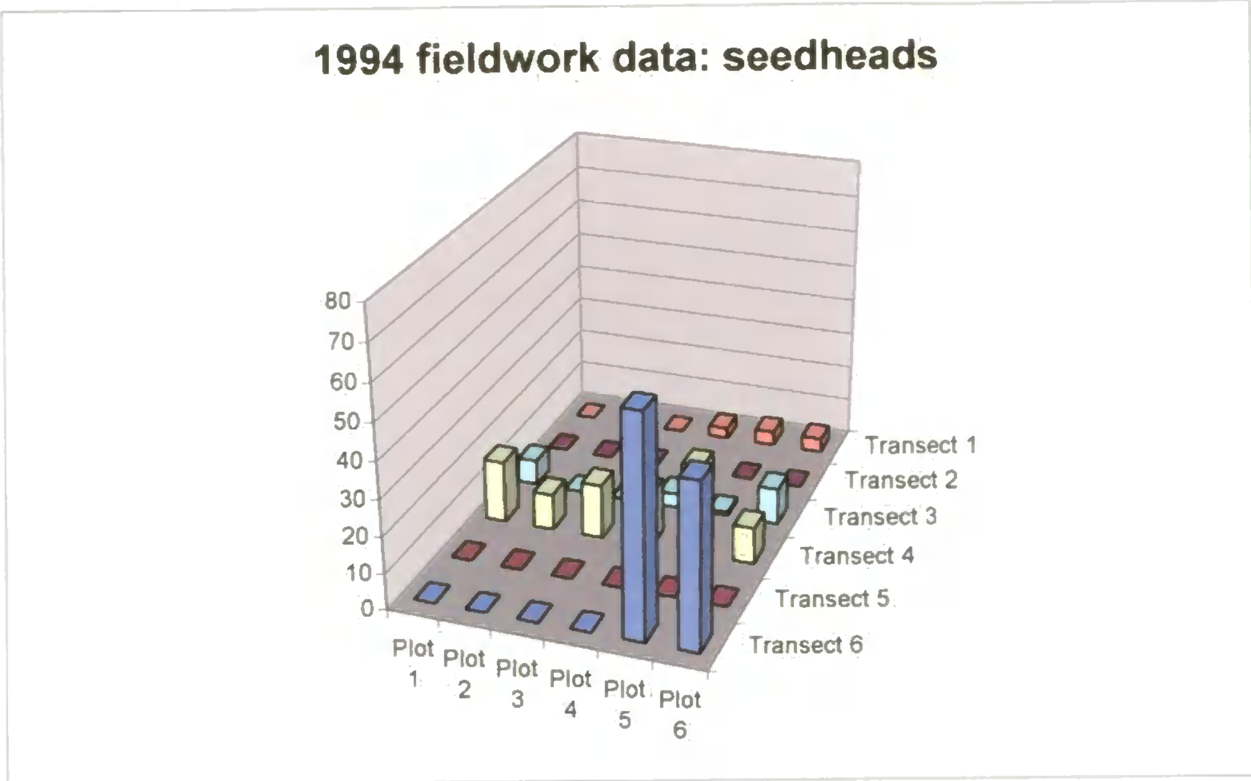
Figure 7.4 Reed density data from South Milton Ley, August 1994



	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6
Transect 6	966.6	1186.0			1113.0	850.0
Transect 5	836.7	283.6			594.7	53.8
Transect 4	2207.7	3379.8	3494.1	1979.3	1598.1	753.1
Transect 3	272.2	698.0	276.2	460.3	76.5	1006.5
Transect 2	0.0	0.0	111.9	105.1	5.2	13.0
Transect 1	36.0	22.3	170.6	719.6	1153.6	620.0

Biomass: grams per square metre

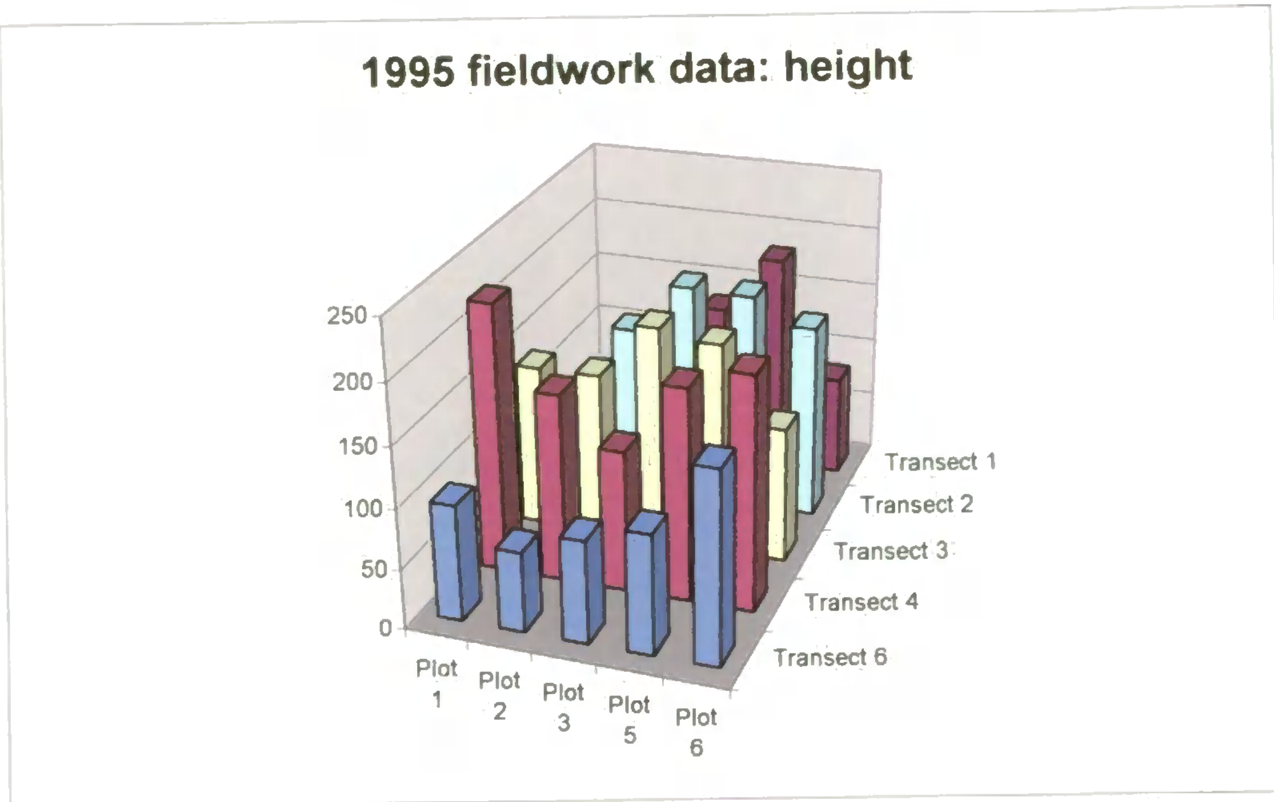
Figure 7.5 Reed biomass data from South Milton Ley, August 1994



	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6
Transect 6	0.0	0.0	0.0	0.0	60.0	45.0
Transect 5	0.0	0.0	0.0	0.0	0.0	0.0
Transect 4	17.0	10.0	15.0	15.0	25.0	10.0
Transect 3	7.0	0.0	0.0	4.0	1.0	10.0
Transect 2	0.0	0.0	0.0	0.0	0.0	0.0
Transect 1	0.0	0.0	0.0	3.0	4.0	4.0

Number of seedheads

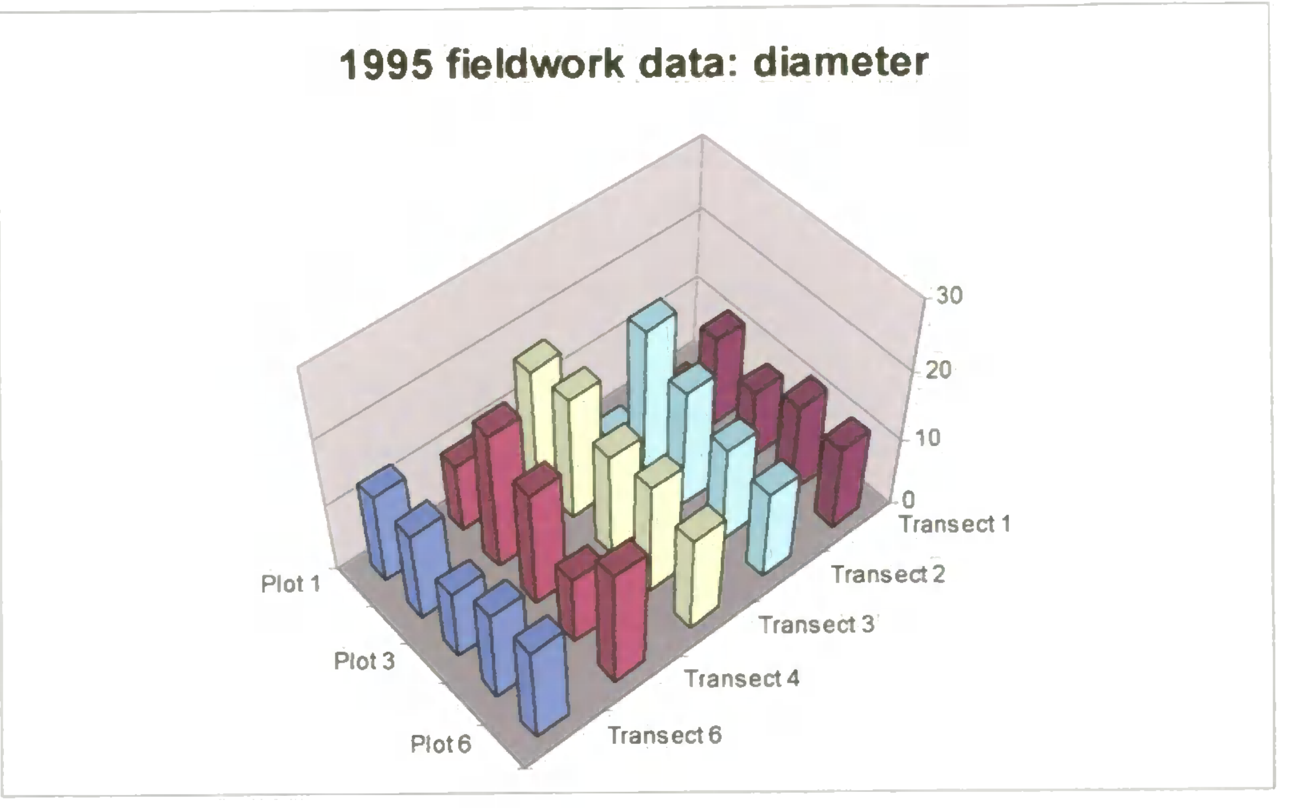
Figure 7.6 Reed seedheads data from South Milton Ley, August 1994



	Plot 1	Plot 2	Plot 3	Plot 5	Plot 6
Transect 6	96.3	66.8	85.0	99.3	159.0
Transect 4	222.5	156.2	116.9	176.0	193.7
Transect 3	135.8	136.3	183.2	176.2	112.9
Transect 2	0.0	142.0	184.9	183.4	162.6
Transect 1	0.0	84.7	134.0	183.6	83.3

Mean reed height: cm $n \leq 10$

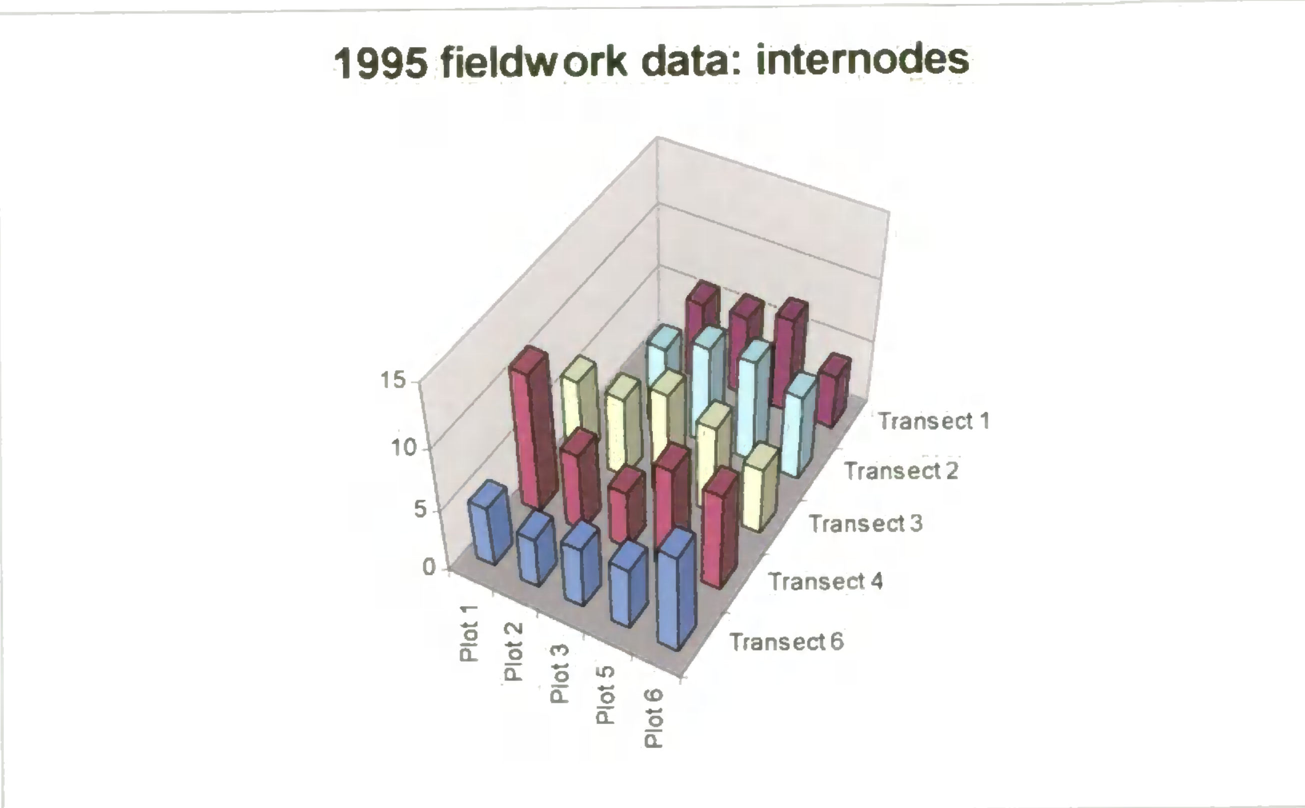
Figure 7.7 Reed height data from South Milton Ley, August 1995



	Plot 1	Plot 2	Plot 3	Plot 5	Plot 6
Transect 6	13.0	13.0	10.0	13.0	14.0
Transect 4	10.0	20.0	17.0	10.0	17.0
Transect 3	17.0	18.0	15.0	16.0	14.0
Transect 2	0.0	21.0	17.0	14.0	13.0
Transect 1	0.0	13.0	10.0	13.0	12.0

Mean reed diameter: mm n ≤ 10

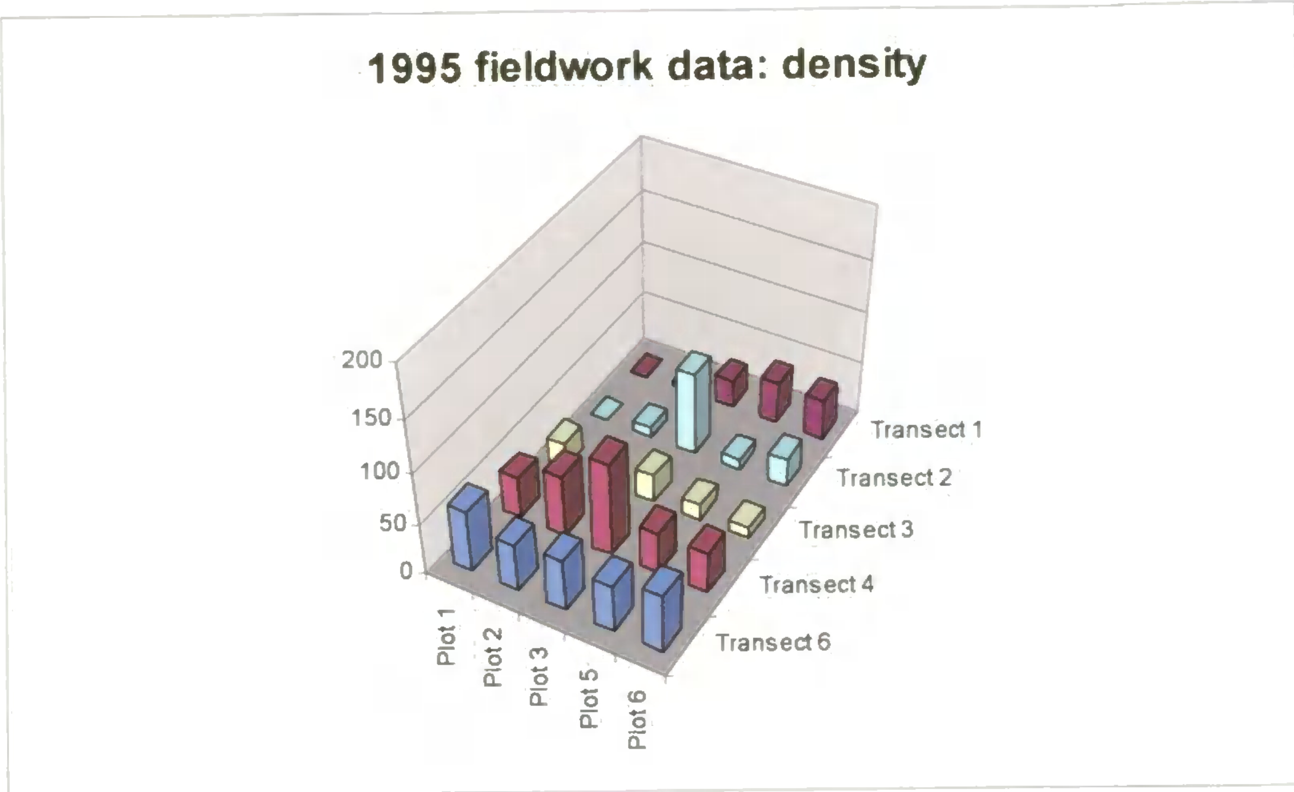
Figure 7.8 Reed diameter data from South Milton Ley, August 1995



	Plot 1	Plot 2	Plot 3	Plot 5	Plot 6
Transect 6	4.9	4.0	4.9	5.0	7.9
Transect 4	11.2	6.3	4.8	8.2	7.9
Transect 3	6.5	6.5	8.3	7.2	5.3
Transect 2	0.0	6.5	7.9	8.2	6.9
Transect 1	0.0	6.3	6.5	7.6	4.4

Mean number of internodes: $n \leq 10$

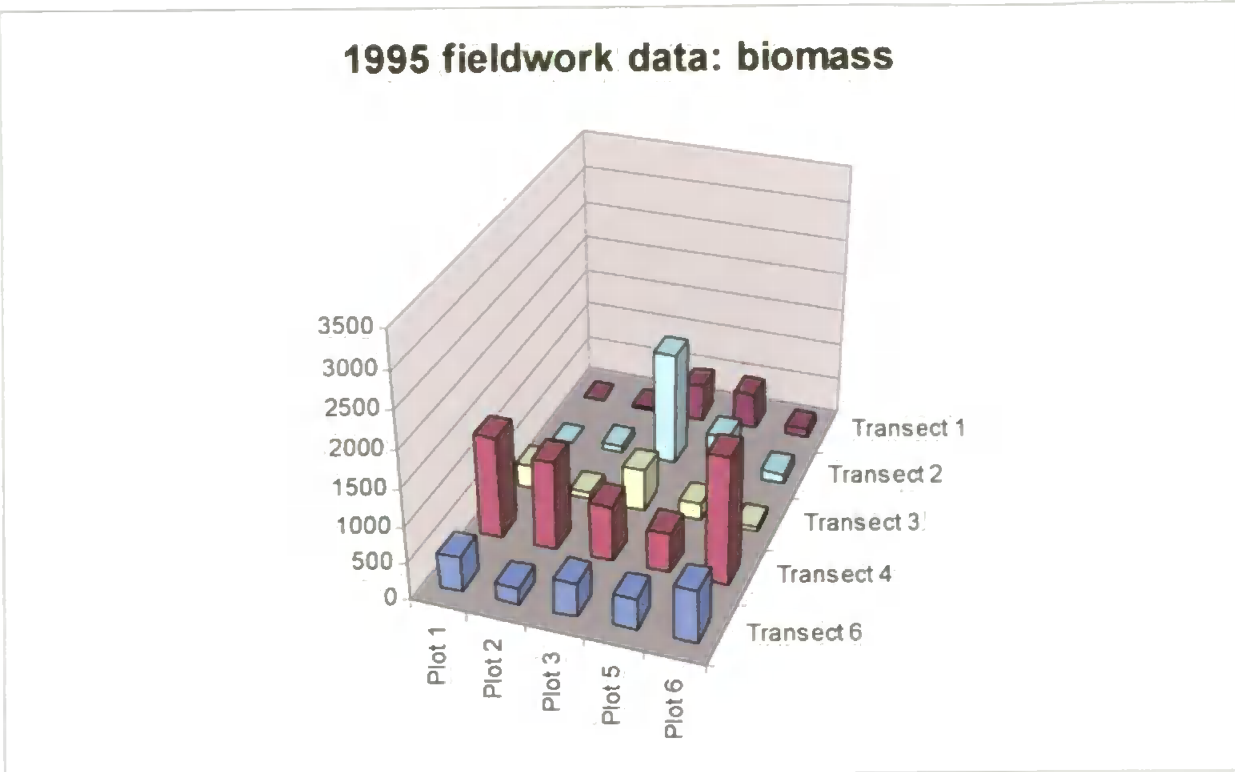
Figure 7.9 Reed internodes data from South Milton Ley, August 1995



	Plot 1	Plot 2	Plot 3	Plot 5	Plot 6
Transect 6	60.0	45.0	50.0	45.0	56.0
Transect 4	40.0	60.0	90.0	40.0	40.0
Transect 3	24.0	5.0	27.0	15.0	10.0
Transect 2	0.0	10.0	80.0	10.0	28.0
Transect 1	0.0	5.0	27.0	41.0	38.0

Density: no. per square metre

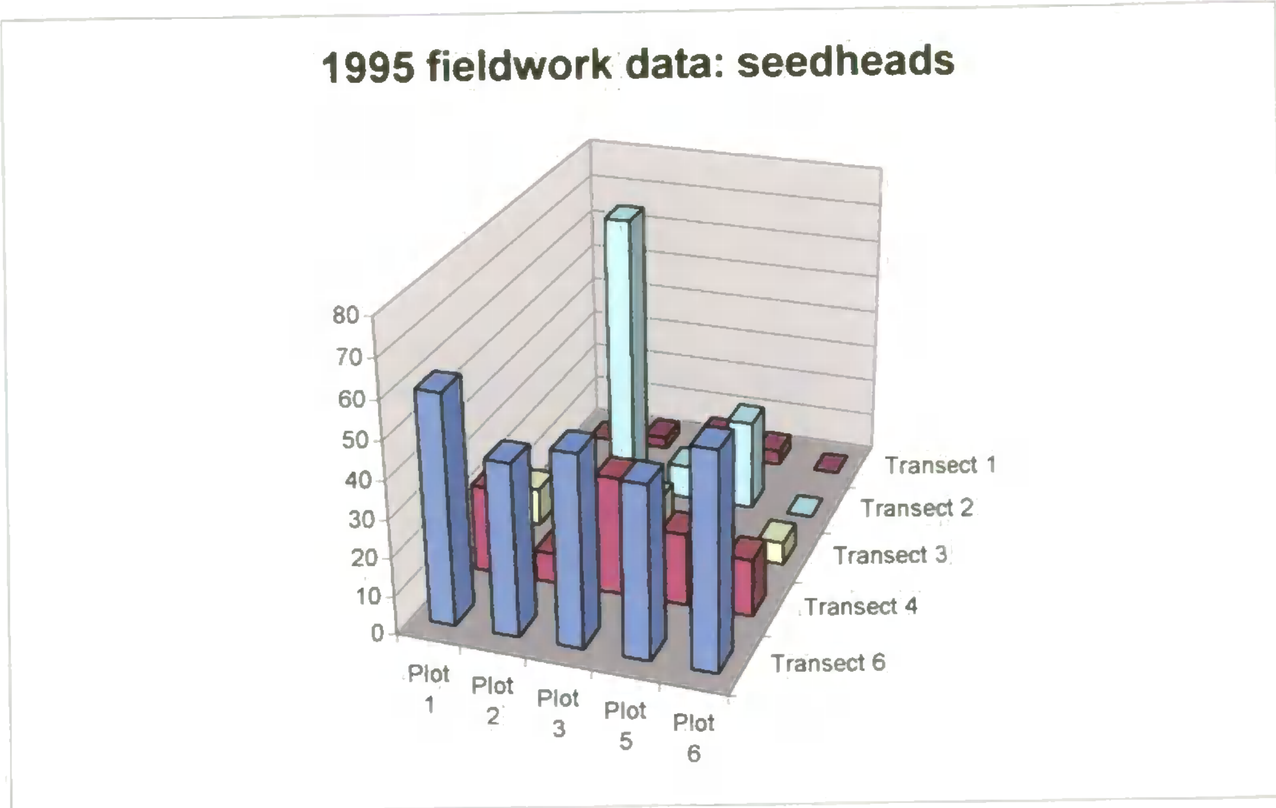
Figure 7.10 Reed density data from South Milton Ley, August 1995



	Plot 1	Plot 2	Plot 3	Plot 5	Plot 6
Transect 6	475.9	223.8	451.6	413.1	700.1
Transect 4	1392.8	1200.0	750.1	543.8	1718.8
Transect 3	308.5	82.2	568.4	229.1	59.8
Transect 2	0.0	95.9	1534.4	516.7	121.7
Transect 1	0.0	15.8	490.4	487.6	124.8

Biomass: grams per square metre

Figure 7.11 Reed biomass data from South Milton Ley, August 1995



	Plot 1	Plot 2	Plot 3	Plot 5	Plot 6
Transect 6	60.0	45.0	50.0	45.0	56.0
Transect 4	23.0	8.0	31.0	19.0	15.0
Transect 3	10.0	3.0	12.0	11.0	6.0
Transect 2	0.0	75.0	9.0	24.0	0.0
Transect 1	0.0	3.0	6.0	4.0	0.0

Number of seedheads

Figure 7.12 Reed seedhead data from South Milton Ley, August 1995

Greatest values for height (**figure 7.7**), diameter (**figure 7.8**) and internodes (**figure7.9**) were found in Transects Two, Three and Four whereas the lowest measurements for these variables were recorded along Transect Six at the seaward end of the Ley. Transects Four and Six contained greatest density and biomass (**figures 7.10 and 7.11**). Transect Six contained the greatest number of seedheads (**figure 7.12**). The lowest measurements for all variables were obtained from Transect One which is situated at the landward end of the Ley. Plots Five and Six contained greatest height and internode figures. Highest diameter values were found in Plots One, Two and Three on the northern edge.

7.3.3 Comparison of Fieldwork Data 1994 and 1995

In order to compare the two sampling years group statistics were studied for all Transects and Plots and plant variables (**Table 7.3**). A t-test to assess equality of means was also undertaken (**Table 7.4**). The results indicate a very significant increase in means from 1994 to 1995 for both diameter ($P < 0.001$) and number of seedheads ($P = 0.007$) (**Table 7.4**). Density decreased from 1994 to 1995 ($P < 0.01$). Height and internodes did not significantly increase from 1994 to 1995 ($P > 0.05$) and biomass did not decrease ($P > 0.05$) in 1995.

In both years Transects Three and Four contained the highest value for height. Lowest height data occurred in Transect One in 1994 and in Transect Six during 1995. During both years Plots One and Six at the margins of the Ley produced greatest height readings and Plot Two produced the lowest. Higher values for diameter measurements occurred in Transects Two, Three and Four and

	Year	N	Mean	Standard deviation	Standard error
Biomass	1	32	782.61	907.68	160.46
	2	25	489.41	494.66	98.93
Density	1	32	57.97	43.56	7.70
	2	25	33.84	24.22	4.84
Diameter	1	32	4.74	2.21	0.39
	2	25	12.52	4.29	0.86
Internode:	1	32	5.08	1.97	0.35
	2	25	6.13	2.44	0.49
Length	1	32	112.51	49.81	8.80
	2	25	130.98	56.95	11.39

Table 7.3 1994 (year 1) and 1995 (year 2) group statistics

Plots Two and Three in 1995. Peak values for density occurred in 1994 (**Figure 7.4**). Transects Four, Five and Six contained the highest values and Transect Three, the lowest. The highest figures for biomass occurred during 1994 were found in Plots One, Two and Three along Transect Four, and for 1995 (**Figure 7.11**) Plots One, Two and Five on the same transect.

		Levene's test for equality of variances		t-test for equality of means		
		F ratio	Sig	t-value	degrees of freedom	Sig (2-tailed)
Biomass	Equal variances assumed	4.334	0.042	1.453	55	0.152
	Equal variances not assumed			1.555	50	0.126
Density	Equal variances assumed	8.548	0.005	2.483	55	0.016
	Equal variances not assumed			2.652	50	0.011
Diameter	Equal variances assumed	3.111	0.083	-8.873	55	0.000
	Equal variances not assumed			-8.25	34	0.000
Internodes	Equal variances assumed	0.468	0.497	-1.804	55	0.077
	Equal variances not assumed			-1.758	46	0.085
Length	Equal variances assumed	0.511	0.478	-1.305	55	0.197
	Equal variances not assumed			-1.283	48	0.206

Table 7.4: Results of t-test to find differences in reed performance between August 1994 and August 1995

7.3.4 Laboratory Data 1996

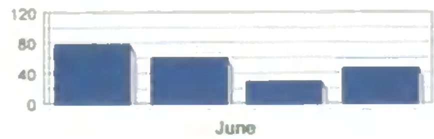
Figures 7.13 - 7.16 represent results of laboratory work carried out on *P. australis*. The Kruskal-Wallis non-parametric test was carried out on data for November where maximum growth was achieved. This test uses the same assumptions as the Mann-Witney test which are explained in **Section 7.3.1**, and tests differences in medians between the four tanks. Owing to lack of space it was not possible to use replicate tanks which would have provided a more accurate indication of the effects of various treatments. An analysis of variance could have then been carried out on the means to test for differences in reed growth between and within each tank. Results of the Kruskal-

Wallis test indicate that Tank One (low N: high P:K) contained greatest values for height (**Figure 7.13**). Tank Three (low N: low P:K) produced the lowest results. Tank Two (high N: low P:K) recorded higher results that Tanks Three or Four (high N: high P:K) ($P = 0.04$). There was no significant difference in diameter (**Figure 7.14**) between tanks ($P > 0.05$). The number of internodes on reeds growing in Tank One was higher than those growing in other tanks. Tank Two contained the lowest number ($P = 0.02$). Maximum reed height occurred in November (Tank One, 115.9cm) and the highest number of internodes (11.3) was also recorded for this tank in November. Tank three contained the lowest results in November for all variables (height 78.7cm, diameter 3.4mm, internodes 8.8, biomass 123.4gm^{-2}) compared with Tank One, Tank Two and Tank Four. Biomass could not be tested by this analysis as only one value was determined for each tank.

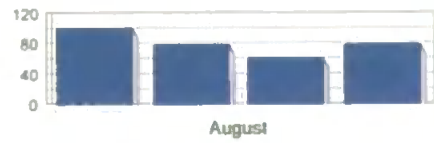
Lodging occurred in reeds growing in Tanks Two, Three and Four. Seed formation did not occur on plants in any of the four tanks.

Chapter Eight further investigates the interaction of water chemistry, water depth and distance from STW on reed growth across plots and transects.

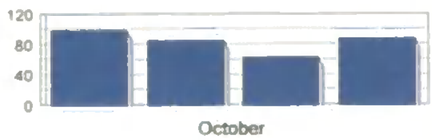
Reed data: height



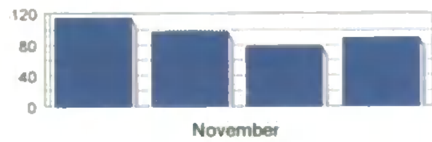
	Tank 1	Tank 2	Tank 3	Tank 4
■ Height cm	80	63	31	51



	Tank 1	Tank 2	Tank 3	Tank 4
■ Height cm	104	82	63	81



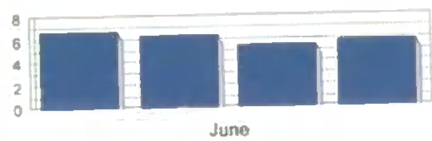
	Tank 1	Tank 2	Tank 3	Tank 4
■ Height	102	89	66	90



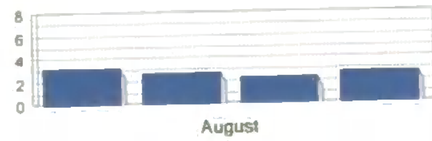
	Tank 1	Tank 2	Tank 3	Tank 4
■ Height	116	100	79	91

Figure 7.13

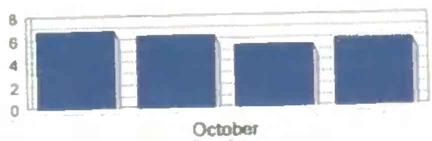
Reed data: diameter



	Tank 1	Tank 2	Tank 3	Tank 4
■ Diameter mn	7	7	6	6



	Tank 1	Tank 2	Tank 3	Tank 4
■ Diameter mr	3	3	2	3



	Tank 1	Tank 2	Tank 3	Tank 4
■ Diameter mn	7	7	6	6

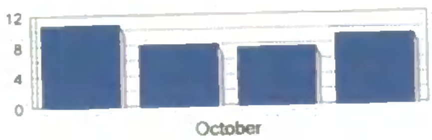
	Tank 1	Tank 2	Tank 3	Tank 4
■ Diameter mn	6	4	3	3

Figure 7.14

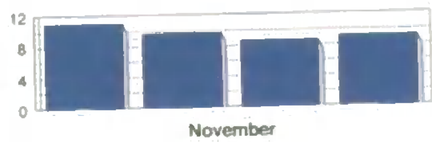
Reed data: internodes

	Tank 1	Tank 2	Tank 3	Tank 4
Internodes	4	4	2	4

	Tank 1	Tank 2	Tank 3	Tank 4
Internodes	6	5	4	5



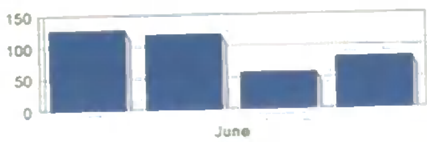
	Tank 1	Tank 2	Tank 3	Tank 4
Internodes	11	8	8	9



	Tank 1	Tank 2	Tank 3	Tank 4
Internodes	11	10	9	9

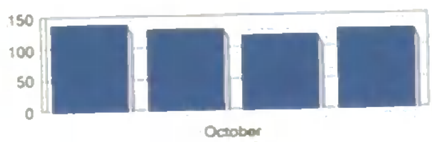
Figure 7.15

Reed data: biomass

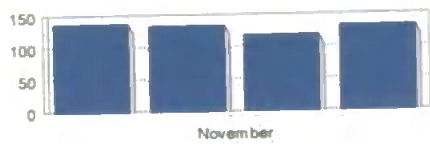


	Tank 1	Tank 2	Tank 3	Tank 4
Biomass gm -2	130	121	60	83

	Tank 1	Tank 2	Tank 3	Tank 4
Biomass gm -2	150	141	128	139



	Tank 1	Tank 2	Tank 3	Tank 4
Biomass gm -2	140	131	122	129



	Tank 1	Tank 2	Tank 3	Tank 4
Biomass gm-2	140	137	123	135

Figure 7.16

7.4 Discussion

7.4.1 Fieldwork

The complex interaction of water level fluctuations and water chemistry are reflected in patterns of reed growth both across South Milton Ley from north to south and along the Ley from landward to seaward. Results for 1994 indicate that in Transect One and Two there are lower reed heights, smaller diameters, biomass and fewer seedhead formations than for transects below the STW. This is the driest part of the Ley. The wettest areas appear to extend from Transect Four to Transect Six and Plots One and Two on the north side and Plots Five and Six on the southern edge. During 1994 these transects contained reeds with highest values for height, diameter, biomass and number of seedheads. However the greatest density of reed growth was found along transect two, which is in the drier area. This may indicate that higher water levels influence the size of reed but that competition for space causes a smaller number to grow in areas of abundant water.

Results for 1995 indicate that diameter and seedhead formation had increased from 1994 whereas density values were lower. Unlike 1994, little variation was found between each transect for height, diameter and number of internodes. However number of seedheads were much greater for transects four and six than for the other sites. This could be explained by the high water level which is maintained at transect four. However transect six, which is situated at the seaward end of the Ley, is more wind exposed than other zones and is subject to considerable fluctuations of water levels.

Another variable that appears to be influencing the growth of the reeds is water chemistry. The tallest reeds with the greatest diameters were found in plots on the northern side of the Ley where surface and sub-surface waters contain the highest concentrations of nitrogen, phosphorus and potassium. Transect six contains reeds which are influenced by high levels of potassium from brackish water.

Boar (1987) found that in growth experiments an increase in shoot height, biomass and density occurred when a low N:K ratio was maintained. Lodging also decreased. The lowest incidence of regression of reeds occurred in areas of Broadland which were subject to sea water inundation.

Results of laboratory work carried out in 1996 appear to support her conclusions. Tank One which contained plants grown in a low N:K ratio medium produced the tallest reeds with the greatest number of internodes. Lodging did not occur in reeds grown in this tank. The influence of phosphorus within the ratio of N:K is difficult to explain. Tank Three which was also supplied with low N:K ratio and also with low P:K ratio produced the lowest results for all variables. It is therefore possible that a low nitrogen to potassium ratio combined with a high phosphorus to potassium ratio (Tank One) is the most beneficial to reed growth. This experiment supports the view of **Boar (1987)** that ratios rather than absolute concentrations are important in the complex chemistry of reed growth.

CHAPTER EIGHT

Statistical relationships between reed performance, water depth and water chemistry

8.1 Methods

Correlation analysis was carried out on data for 1994 and 1995 between reed variables and between reed and chemistry data. The next analysis tested how each reed variable was affected by water chemistry. A regression analysis was undertaken for each reed variable and for water chemistry data and indicator variables were created for transects and plots. A backward elimination regression was carried out for each reed variable and the least significant t-values from the results were removed. Analysis of covariance (ANCOVA) was then carried out on the factors (transects and plots) and covariables (water chemistry and water depth) remaining in each regression.

8.2 Results

8.2.1 Data for 1994

Table 8.1 displays correlations between reed and chemistry data. High correlation values are indicated in bold. A high negative correlation is found between TON and biomass (-0.708). All the correlation coefficients in this case are negative (except between biomass diameter and SRP) which may indicate that high concentration of SRP and TON could be associated with short, thin reeds with low biomass **Vong (1994)**.

	Height	Diameter	Internodes	Biomass	Density
SRP	-0.500	0.494	-0.422	0.523	-0.355
TON	-0.598	-0.632	-0.452	**-0.708**	-0.425

Significant at 0.001 level (10% probability significantly different from zero)

Table 8.1: Correlation coefficients between reed variables & chemical data 1994

The results of the ANCOVA for reed variables are recorded in **Tables 8.2 - 8.6**. A significant difference for height can be noted both between plots and between transects (P. value < 0.001), and negative relationship between height and TON (coefficient -5.067) **(Table 8.2)**. Diameter results **(Table 8.3)** indicate that transect, plot, SRP and TON affect this variable. Again the influence of

TON is negative. Transect and plot variation for internode values is indicated by **Table 8.4.** SRP, TON, transect and plot affect biomass **(Table 8.5)**. TON coefficient is again negative (-263.32). Results for density **(Table 8.6)** show that plot and TON vary with the density of reed growth and that as TON increases (negative coefficient -3.270) density decreases.

Source of variance	Degrees of freedom	F ratio	Sig	Coeff	Standard deviation	t-value	Sig
Distance from STW	1	14.83	0.000	0.040	0.01	3.850	0.000
SRP	1	2.52	0.114	4.840	3.05	1.590	0.114
TON	1	13.81	0.000	-5.067	1.36	-3.720	0.000
PLOT	5	4.57	0.000	-	-	-	-

Table 8.2: Ancova for height 1994

Source of variance	Degrees of freedom	F ratio	Sig	Coeff	Standard deviation	t-value	Sig
Distance from STW	1	4.72	0.031	0.001	0.00	2.170	0.031
SRP	1	24.21	0.000	0.601	0.12	4.920	0.000
TON	1	52.37	0.000	-0.395	0.55	-7.240	0.000
PLOT	5	5.07	0.000	-	-	-	-

Table 8.3: Ancova for diameter 1994

Source of variance	Degrees of freedom	F ratio	Sig	Coeff	Standard deviation	t-value	Sig
Distance from STW	1	10.24	0.002	0.002	0.00	3.200	0.000
SRP	1	2.47	0.117	-0.230	0.15	-1.570	0.002
TON	1	0.02	0.882	-0.010	0.07	-0.150	0.117
PLOT	5	8.66	0.000	-	-	-	0.882

Table 8.4: Ancova for internodes 1994

Source of variance	Degrees of freedom	F ratio	Sig	Coeff	Standard deviation	t-value	Sig
Distance from STW	1	15.02	0.000	-0.574	0.15	-3.880	0.000
SRP	1	114.02	0.000	461.870	43.25	10.680	0.000
TON	1	185.72	0.000	-263.320	19.32	-13.630	0.000
PLOT	5	5.39	0.000	-	-	-	-

Table 8.5: Ancova for biomass 1994

Source of variance	Degrees of freedom	F ratio	Sig	Coeff	Standard deviation	t-value	Sig
Distance from STW	1	1.57	0.211	0.012	0.01	1.250	0.211
SRP	1	1.52	0.218	3.352	2.72	1.230	0.218
TON	1	7.26	0.007	-3.270	1.21	-2.700	0.007
PLOT	5	11.36	0.000	-	-	-	-

Table 8.6: Ancova for density 1994

8.2.2 Data for 1995

Table 8.7 displays the correlation results for water chemistry and plant variables. A strong negative correlation was found between K concentration and length and diameter. This may mean that high K concentration is associated with short reeds and small diameters. However, K has a high positive relationship with density. Height is highly correlated with diameter and biomass and density is positively correlated with biomass and TDN. SRP and TON do not exhibit a strong relationship with any of the reed variables.

		Length	Diameter	Biomass	Density
SRP	Pearson correlation	* -0.142	0.008	* -0.161	0.027
	Sig. (2-tailed)	0.036	0.908	0.150	0.687
TDP	Pearson correlation	0.058	-0.112	* -0.143	0.122
	Sig. (2-tailed)	0.397	0.100	0.031	0.066
TON	Pearson correlation	* -0.155	0.059	* -0.163	0.110
	Sig. (2-tailed)	0.022	0.390	0.013	0.097
TDN	Pearson correlation	* -0.175	-0.053	-0.121	** 0.292
	Sig. (2-tailed)	0.010	0.442	0.068	0.000
K	Pearson correlation	** -0.452	** -0.216	* -0.157	** 0.358
	Sig. (2-tailed)	0.000	0.001	0.017	0.000
LENGTH	Pearson correlation	1.000	** 0.231	** 0.236	-0.055
	Sig. (2-tailed)		0.001	0.000	0.421
DIAMETER	Pearson correlation	** 0.231	1.000	* 0.166	-0.092
	Sig. (2-tailed)	0.001		0.014	0.177
BIOMASS	Pearson correlation	** 0.236	* 0.166	1.000	** 0.457
	Sig. (2-tailed)	0.000	0.140		0.000
DENSITY	Pearson correlation	-0.055	-0.092	** 0.457	1.000
		0.421	0.177	0.000	

** Correlation is significant at the 0.01 level (2 tailed) 1% level (1% probability sig. different from zero)

* Correlation is significant at the 0.05 level (2-tailed) 5% level (5% probability sig. Different from zero)

Table 8.7 - correlation coefficients between reed variables and chemistry data 1995

Tables 8.8 - 8.16 display results for the ANCOVA analysis. **Table 8.8** displays the results for height. The height of reeds in Transect Two, Three and Four are significantly different from those in Transect Six. **Table 8.9** shows that transects, SRP, TDP, TON, K and water depth influence diameter size. Column 8 describes the coefficient rate of change per unit amount of variable. Therefore as SRP and TDP increase, diameter decreases. As TON, K and depth increase diameter also increases. Water depth is most significant (P-value < 0.001). **Table 8.10** compares diameter size in adjacent transects. The results show that Transects Four and Six are significantly different from each other.

Table 8.11 indicates that there is a significant difference between Transects Four and all other transects for numbers of internodes. Multiple comparison LSD test **(Table 8.12)** show that Transects Four and Six are significantly different from each other. **Tables 8.13** and **8.14** display the results for biomass. LSD comparisons **(Table 8.14)** reveal that Transect Four has different mean biomass to all other transects. Results for density **(Table 8.15)** show that TDN and plot significantly affect this reed variable. **Table 8.16** indicates that Plot Three is significantly different from Plots Two and Four.

Source of variance	Degrees of freedom	F ratio	Sig	Parameter	Coeff	Standard deviation	t-value	Sig
Transect	4	3.52	0.027	Transect one	20.120	23.84	0.844	0.410
				Transect two	66.945	23.84	2.808	0.012
				Transect three	47.600	22.48	2.118	0.048
				Transect four	71.780	22.48	3.194	0.005

Table 8.8: Ancova for height 1995

Source of variance	Degrees of freedom	F ratio	Sig	Parameter	Coeff	Standard deviation	t-value	Sig
Transect	4	4.83	0.013	Transect one	57.175	15.54	3.680	0.003
SRP	1	19.10	0.007	Transect two	52.892	14.08	3.756	0.002
TDP	1	19.29	0.001	Transect three	61.146	14.78	4.137	0.001
TON	1	6.69	0.023	Transect four	56.288	14.06	4.004	0.001
K	1	17.93	0.001	SRP	-13.073	4.11	-3.179	0.007
Depth	1	42.83	0.000	TDP	-28.729	6.54	-4.392	0.001
				TON	4.745	1.84	2.586	0.023
				K	1.872	0.44	4.235	0.001
				Depth	4.644	0.71	6.544	0.000

Table 8.9: Ancova for diameter 1995

Transect difference	St error	Significance
Transect one vs transect two	12.22	0.732
Transect two vs transect three	9.13	0.515
Transect three vs transect four	8.14	0.925
Transect four vs transect six	13.00	0.001

Table 8.10: Contrast results for diameter

Source of variance	Degrees of freedom	F ratio	Sig	Parameter	Coeff	Standard deviation	t-value	Sig
Transect	4	1.73	0.187	Transect one	0.860	1.05	0.821	0.422
				Transect two	2.035	1.05	1.944	0.068
				Transect three	1.420	0.99	1.439	0.167
				Transect four	2.340	0.99	2.371	0.029

Table 8.11: Ancova for internodes 1995

Transect difference	St error	Significance
Transect one vs transect two	1.10	0.301
Transect two vs transect three	1.05	0.564
Transect three vs transect four	0.99	0.364
Transect four vs transect six	0.99	0.029

Table 8.12: Contrast results for internodes

Source of variance	Degrees of freedom	F ratio	Sig	Parameter	Coeff	Standard deviation	t-value	Sig
Transect	4	4.23	0.014	Transect one	-173.250	262.67	-0.660	0.518
				Transect two	114.275	262.67	0.435	0.669
				Transect three	-257.300	247.65	-1.039	0.313
				Transect four	668.200	247.65	2.698	0.015

Table 8.13: Ancova for biomass 1995

Transect difference	Standard error	Significance
Transect one vs transect two	276.88	0.313
Transect two vs transect three	262.67	0.174
Transect three vs transect four	247.65	0.002
Transect four vs transect six	247.65	0.015

Table 8.14: Contrast results for biomass

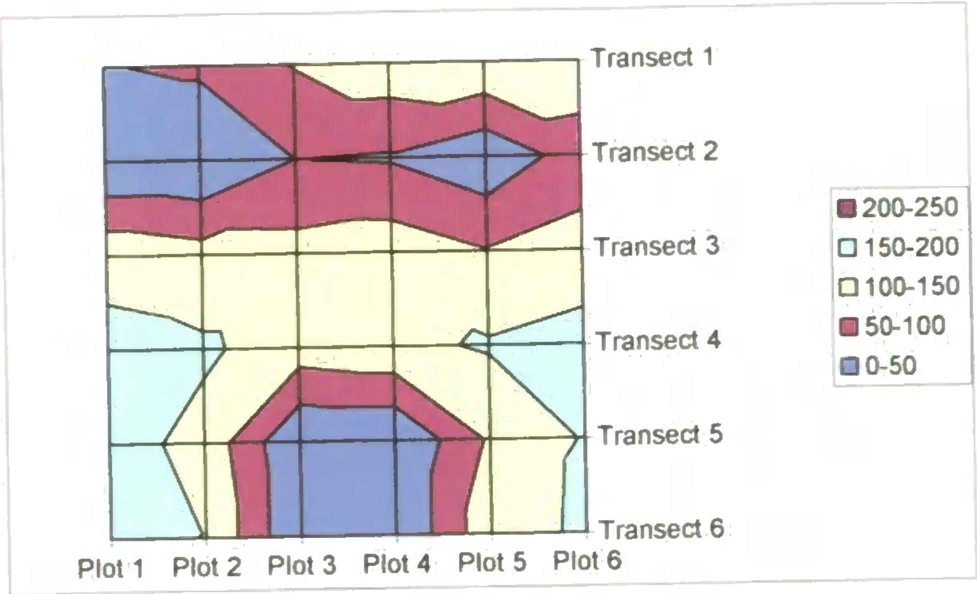
Source of variance	Degrees of freedom	F ratio	Sig	Parameter	Coeff	Standard deviation	t-value	Sig
TDN	1	21.30	0.000	TDN	0.753	0.16	4.615	0.000
Plot	4	4.82	0.009	Plot one	9.845	11.19	0.880	0.391
				Plot two	-10.605	9.68	-1.096	0.288
				Plot three	30.489	9.92	3.074	0.007
				Plot five	-0.737	9.70	-0.076	0.940

Table 8.15: Ancova for density 1995

Plot difference	Standard error	Significance
Plot one vs Plot two	11.21	0.086
Plot two vs Plot three	9.98	0.001
Plot three vs Plot four	9.78	0.005
Plot four vs Plot six	9.70	0.940

Table 8.16: Contrast results for density

Figures 8.1 to 8.5 display contour graphs. Transect 5 and Plot 4 have been included in 1995 graphs (although no data were obtained from these areas) to allow comparison with similar areas. The graphs compare patterns of growth between the two years. They illustrate the complexity of analysing differences in reed variables and demonstrate the difficulty in deducing a pattern of change over the two sampling years.



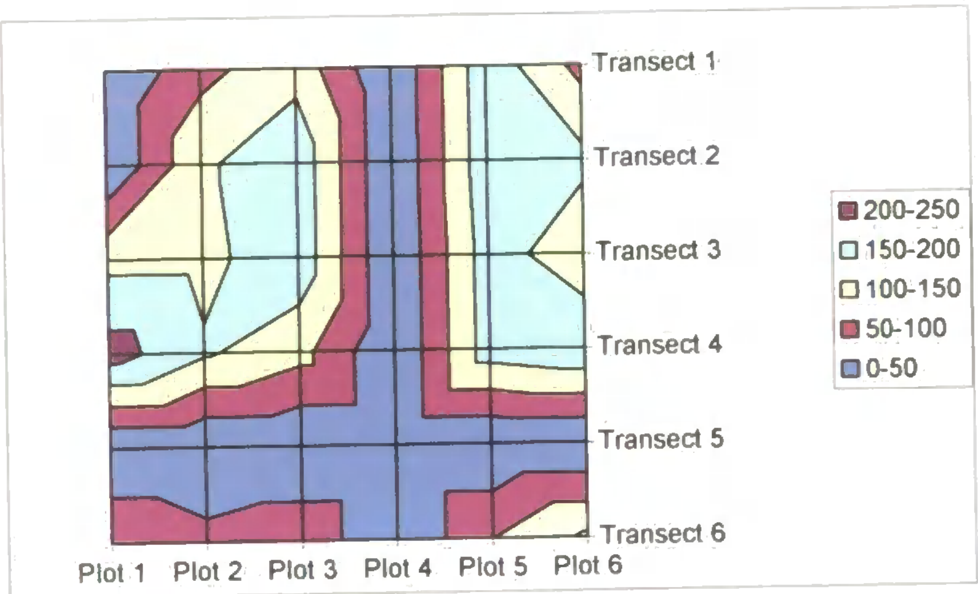
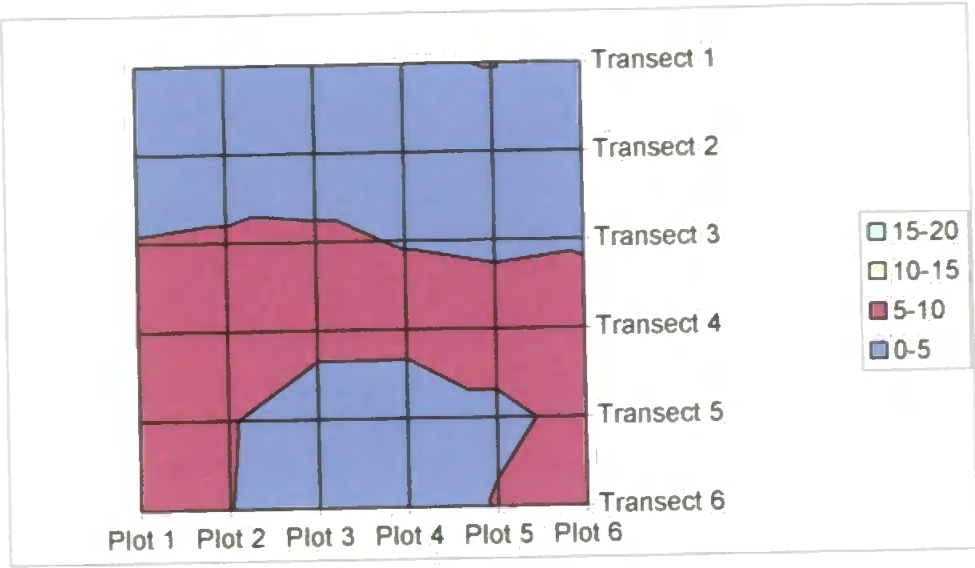


Figure 8.1: Comparison of mean reed height (cm) (n=10) August 1994 (top) and 1995



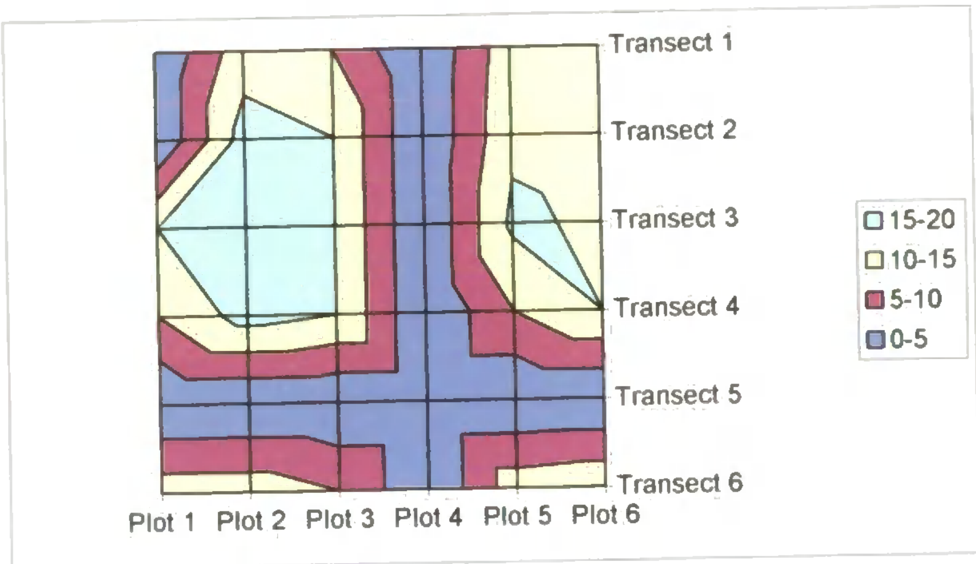
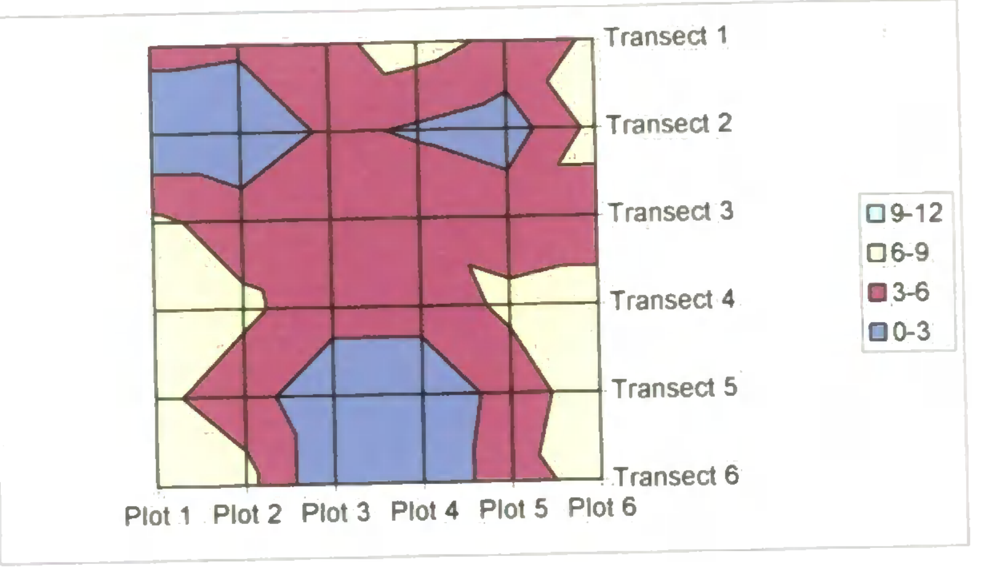


Figure 8.2: **Comparison of mean reed diameter (mm) (n=10) August 1994 (top) and 1995**



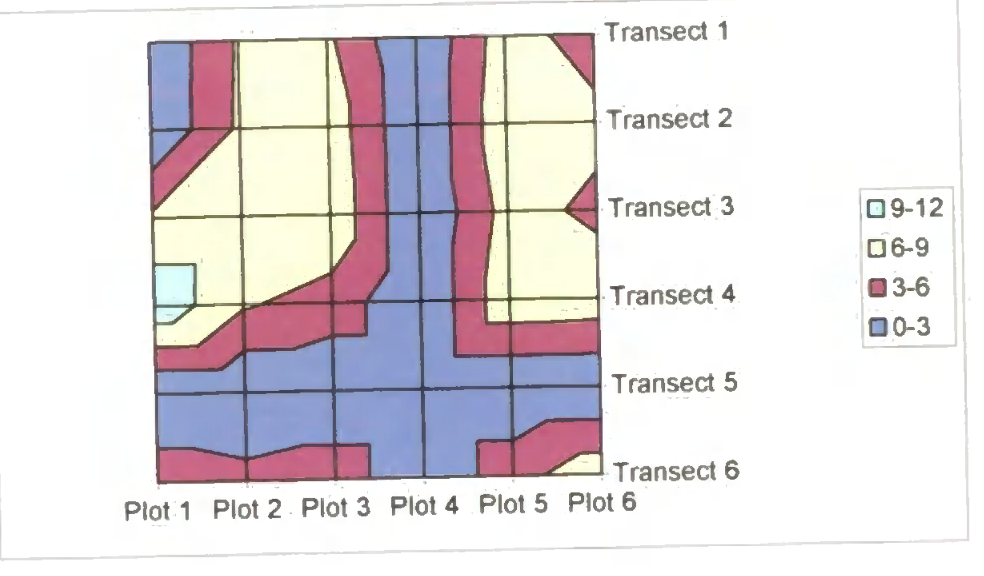
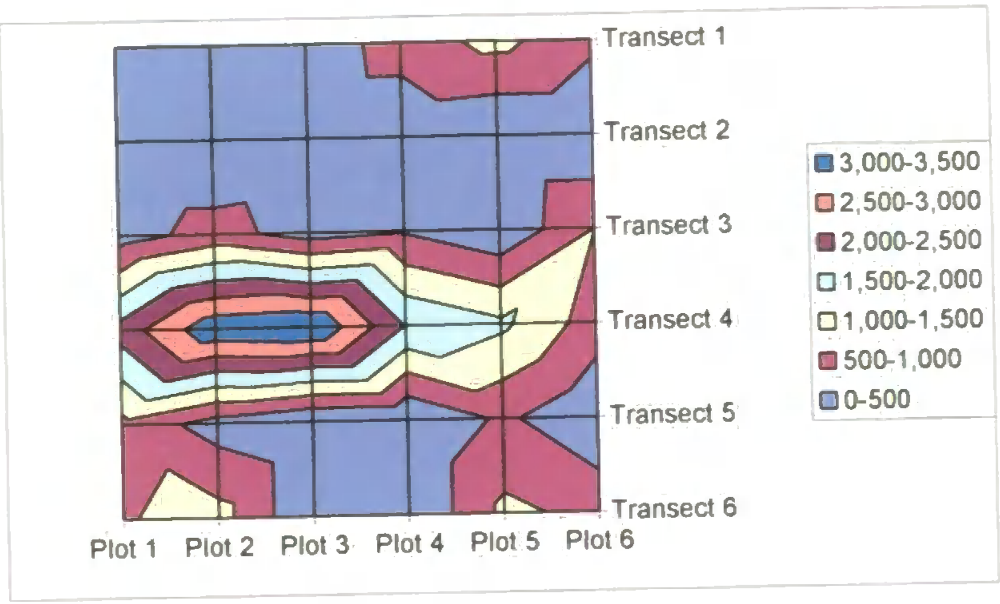


Figure 8.3: Comparison of mean reed internodes (number per stem) August 1994 (top) and 1995



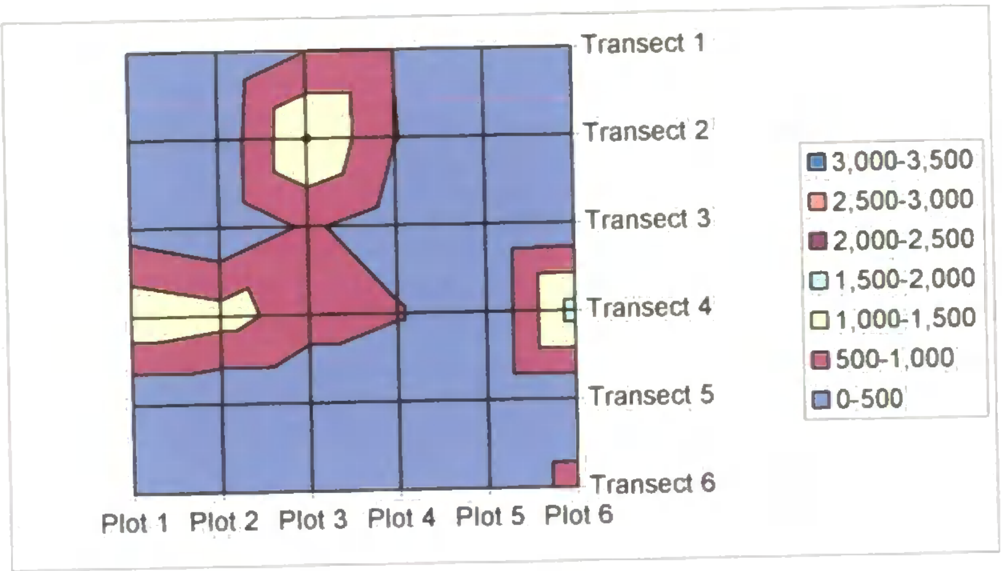
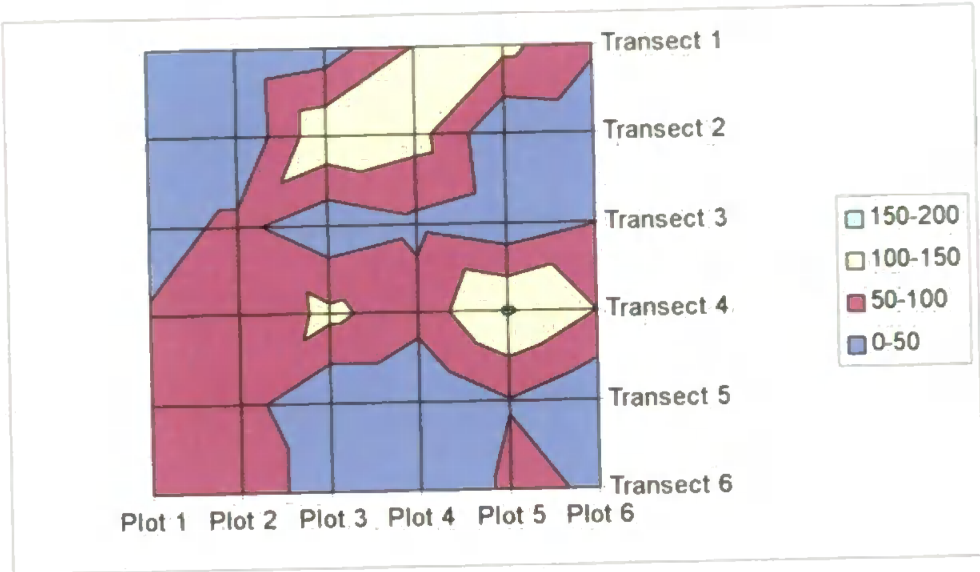


Figure 8.4: Comparison of reed biomass (n=10) g m^2 August 1994 (top) and 1995



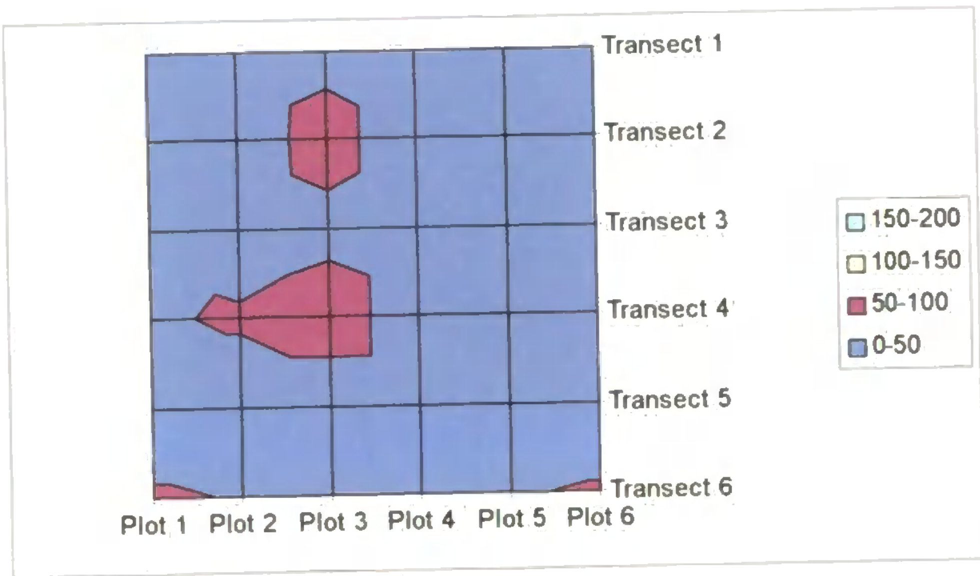


Figure 8.5: Comparison of density (number m^{-2}) August 1994 (top) and 1995

CHAPTER NINE

Discussion

This research set out to find whether conditions in which reed is known to decline occur at South Milton Ley and in particular whether increased nutrient loadings from South Milton STW are causing changes to plant growth and water quality.

Within this framework various hypotheses were tested in order to explore major interactions within the wetland:

i) can changes in plant characteristics be linked to water chemistry ?

ii) can variation in ratios of N:P:K cause changes in reed growth ?

iii) does water level affect reed growth ?

iv) in what ways do these factors interact ?

Examination of plant growth data for 1994 indicated that reeds from that year are thinner with fewer seedheads than those of 1995. However density is greater. TON, SRP and K concentrations were higher in 1994. **Boar (1987)** found in laboratory experiments that biomass increased with concentrations of TON up to 6 mg l^{-1} and density increased to the greatest extent between 6-12 mg l^{-1}. Values found at South Milton Ley are higher than these (mean daily concentration 8 mg^{-1} – 18 mg l^{-1}), although the effect of TON on shoots still appears to be to increase biomass. Boar's studies indicate that concentrations of K above 18 mg l^{-1} appeared to inhibit the uptake of TON. At low N:K ratios, shoot height increased. From June to December 1995 concentration of K at South Milton Ley was higher than 18 mg l^{-1} and a low N:K ratio was noted. Laboratory results from this research support Boar's conclusion and also suggest that both low N:K and high P:K ratios produce taller plants.

Results of statistical analysis that investigated the interaction of hydrology, water chemistry and reed growth over the two years did not show a conclusive link between the various factors. Correlation analysis for 1994 indicated that high concentrations of SRP and TON could be associated with thin short reeds with low biomass. Analysis for 1995 suggested that elevated K values could produce a high density of short reeds. Transect four and six were significantly different from each other for all plant variables. This could be linked to water depth. Transect four is the wettest area of the reedbed and produced reeds with greatest height, diameter and biomass during 1994. Transect six is influenced by seawater inundation and in 1995 produced the highest number of seedheads. This transect may contain an ecotype of 'fine' reeds as described by **Lissner** ***et al.*** **(1999)**, who found that reeds growing in Mediterranean areas had adapted to high salinity by increasing their transpiration rates.

Comparison of water budgets for 1994 – 1996 indicated that 1994 was the wettest year and 1995 was the driest. Most of the rainfall in 1994 occurred during September to December after plant analysis and so would not have influenced that year's growth, whereas high water levels at the beginning of the 1995 growing season may have produced reeds with greatest number of seedheads during that year. Water depth was found to have the most significant affect on diameter (P value < 0.001). As water levels increased, so did diameter size (refer to **Chapter 8, Table 8.9**).

Boar (1997) found that there was a direct relationship between K content of dead and living stems and K concentrations in water. However, she also found that there were few positive correlations between nitrogen and phosphorus content of dead and living reed stems and nitrogen and phosphorus concentration of water. She suggested that fluctuations in redox potential could regulate uptake of nitrogen.

In brackish marshes with mineral substrate (ie those habitats most comparable to South Milton Ley) ratios of 5:1 N:P were found which could indicate that nitrogen was scarce. However in freshwater peats ratios of 14:1 suggest that in these habitats phosphorus is more limiting. In a five-year study, **Boar (1996)** found that despite differences in nitrogen accumulation in shoots, nitrogen storage in roots did not change. This suggests that mature stands use 'open nutrient' cycles where new nutrients are not conserved for reuse, but may be shed in dead stems which has implications for the efficiency of nutrient retention where it is assumed that wetlands can be used to remove nutrients by net storage and growth. These studies may explain the difficulty in understanding the complex effect of water chemistry on plant growth. However it appears to play a key part together with water fluctuations.

Rea (1996) suggested that one of the factors providing for lack of regeneration of reed growth could be the stabilisation of water regimes. This factor increases overall submergence and reduces CO_2 and O_2 availability increasing phytotoxicity and hypoxia. She therefore suggests that a combination of high water and high nutrient levels could cause lack of regeneration. Reeds fail to establish seedlings when submerged or growing within dense stands. Therefore periodic flushing and exposure of sediments to allow drying in spring/summer appears to favour regeneration.

South Milton Ley has a fluctuating water regime but if the sand-bar is closed for most of the year reeds do not experience a period of sediment drying. The sand-bar is usually breached during westerly gales which normally occur during the winter months. Therefore low water levels are more likely to occur during the dormant growth period. In contrast during the spring water levels rise as the sand-bar forms and this may inhibit the growth of seedlings. When summer water levels are high the sediments are constantly anoxic which can prevent rhizosphere oxidation. Litter decomposition can expose reeds to the phytotoxic products of fermentation throughout the growing season. The reedbed at South Milton Ley appears to be a mature stand which does not have the conditions for regeneration. This would become important if the reedbed was to regress.

Eutrophication therefore does not appear in general to have a direct effect on reed regression but when linked with high constant water levels can be a key factor. **Brix (1999)** found that in highly eutrophic habitats where reed was declining, a surplus of phosphorus over nitrogen was observed. During August 1999 at South Milton Ley, a bloom of *Oscillatoria* sp. was noted at the seaward end. This coincided with a period of high SRP concentrations (11 mg l^{-1}) in the effluent from the sewage treatment works. Regrettably, nitrogen data are no longer collected by the Environment Agency so the concentration of this element was not known at the time. The enlarged sewage treatment works was designed to serve a maximum population of 2,000 (approximately five times the numbers served by the previous facility) and as the primary and secondary processes are based on the same methods as before it seems unlikely the extended plant will achieve its objective of no increase in nutrient levels as compared with the previous works. As the volume of visitors attracted to the region increases there will be a consequential rise in the volume of effluent during the peak summer months and the phosphorus loads to the Ley may then increase further. This could have a significant affect on the status of the wetland especially if the algal bloom becomes a regular occurrence.

Ostendorp (1992) and **Yamasaki (1993)** suggested that algal masses could be detrimental to reeds reducing growth mechanically or chemically by producing phytotoxins when the algae decay. Increased nutrients not only enhance the productivity of the reedbed but also accelerate litter accumulation. Waterlogging of reed litter also produces anaerobic conditions for decomposition thus exposing reeds to greater levels of phytotoxins and a reduction in O_2 availability to roots and rhizosphere.

The loading of nitrogen, phosphorus and potassium to the Ley appears to be increasing although at present there are no signs of reedbed regression. This is possibly because the peculiar water regime has prevented the build up of nutrients. However the *Oscillatoria* bloom may suggest that key factors for decline are developing and the occurrence of the bloom may indicate that the status of the reedbed is vulnerable and could change for the worse.

The use of wetlands as hydrochemical buffers in the treatment of wastewater and polluted waters together with the effects of anthropogenic disturbance such as drainage and fertilising are topical issues internationally. Knowledge of these disturbances is needed if natural wetlands are to be protected and those that are degraded restored. General principles of wetland function learned from the study of South Milton Ley can be applied to other sites but management strategies need to be specifically adapted to particular wetland types. Without information about the different variables which interact in a wetland community management decisions cannot be made responsibly.

The capacity of a wetland to deal with or 'buffer' a disturbance such as increased fertility depends on seasonal, diurnal and historic inputs, outputs and storage within the ecosystem. The transfer rates of nutrients from storage compartments (vegetation, detritus, fauna, micro-organisms and sediments) to throughflowing wetland water governs the ability to retain nutrients. When changes in wetland storage compartments are minimal (inputs $\simeq$ outputs) a steady state nutrient flow is reached and the wetland's capacity to remove nutrients may be negligible. If the ability of storage compartments to transfer nutrients is reduced, for example because of changes in plant growth due to increased nutrient loadings, nutrient reduction by the wetland system as whole will be affected (**Howard-Williams 1985**).

The question whether a wetland is a 'sink' or 'source' for nutrients depends on the equilibrium between input and the binding capacity of the system (**Golterman 1993**). This may vary over seasons and change over years depending on events in the wetland.

The importance of wetland 'compartments' in nutrient cycling varies with different nutrients. Of key importance in the nitrogen cycle are bacteria that convert nitrogen from organic to inorganic forms. All conversions are sensitive to sediment redox potential (measure of aeration). Wetland sediments are often anaerobic and highly reducing which results in accumulation of ammonium. Bacterial conversion of ammonium to nitrate (nitrification) requires an aerobic environment and denitrification (conversion of nitrate to nitrogen gas) needs anaerobic conditions. Conditions for maximum denitrification (N loss to the system) are unusual requiring low redox combined with oxidized nitrogen. Addition of nutrients can change wetland soil environments and this can affect sites for denitrification.

Comparisons with other sites (**Chapter six, 6.6 Discussion**) show South Milton Ley to be nutrient rich. During the study years more nitrogen entered the system than left which indicates nitrogen loss by denitrification and uptake by vegetation. During 1995 the wetland acted as a source of nitrogen. Various conditions could have caused this. Hydrological regime is very important to denitrification. High water levels creating anoxic environments are needed which may result in denitrification occurring in 'wet-spots' within certain areas of the site. **Maltby *et al.* (1995)** found that wetting and drying of wetland soil causes 'flushes' of denitrification and that fast flow rates result in residence times which are far too short for denitrification processes to occur.

Wetlands have been considered 'sinks' for phosphorus because this element is fixed and retained in sediments (phosphate ions are removed from solution by chemical reaction in an oxidized environment). Vegetation can affect the oxygen level in the water column and littoral regions of lakes with their associated plants can dominate the phosphorus cycle (**Wetzel 1983**). However, phosphorus can be released into wetland waters by mobilization of sediments and from decomposing vegetation. Both processes occur by reduction of iron oxyhydroxides under waterlogged anaerobic conditions.

During the summer months SRP transformation processes appear to be occurring at South Milton Ley because inputs were approximately equal to outputs but during autumn and winter months the Ley acted as a source for this nutrient which reinforces the idea that wetlands may not provide suitable nutrient 'sinks' for phosphorus during winter months and annual phosphorus storage may be low.

A seasonal pattern for K assimilation cannot be deduced. Retention of this element within the wetland does not appear to be occurring and the Ley is exporting more potassium than the amount it is receiving.

Howard-Williams (1985) suggests that if a wetland is acting as a nutrient sink in any pathway other than denitrification it is not in a 'steady-state'. Storage compartments have finite boundaries and when they are full the capacity to absorb nutrients breaks down. Changes with time can be expected which include plant species composition, alteration in productivity and changes to the consumers and detritivores.

Hydrology and fertility are the key factors that determine wetland types (**Keddy 2000**). Human impact on these factors can 'stress' the ecosystem and can change the function or species composition. A steady increase of eutrophication from sewage effluent, fertilizers, run-off from agricultural land and atmospheric deposition combined with drainage, levees and dams are reducing wetlands to eutrophic types with stable water levels (**Keddy 2000**). These changes are global. Comparisons of various ecosystems reveal a list of 'stresses' resulting from human activities (**Table 9.1**) that are common to different wetland ecosystems.

Enrichment/eutrophication
Organic loading and reduced dissolved oxygen
Contaminant toxicity
Acidification
Salinization
Sedimentation/burial
Turbidity/shade
Vegetation removal
Thermal alteration
Dehydration
Inundation
Fragmentation of habitat
Other human presence

Table 9.1 Stressors potentially occurring in wetlands

*Source: **Keddy (2000)** after **Adamus (1992)***

At its present nutrient loading rate the natural Ley does not appear to be buffering wetland waters. In addition the efficiency of the RBTS to reduce nutrient loadings and in turn 'buffer' the natural Ley is declining. **Shaver and Melillo (1984)** found that as nutrient concentrations in wetland waters increased the rate of nutrient uptake by plants declined. If the ability of the Ley to 'absorb' the effects of nutrient enrichment declines, changes in species composition and productivity will occur. An increase in reed growth may raise nutrient storage but higher productivity will be limited spatially and hydrologically. Species changes may include proliferation of fast growing plants such as filamentous algae which may have deleterious effects particularly on redox conditions. It is perhaps inevitable that increased long-term nutrient loadings will have detrimental effects on the Ley.

This conclusion emphasizes the importance of the link between ecosystem functioning and environmental controls. A management strategy is required that aims for nutrient reduction and incorporates hydrological monitoring to ensure conditions exist for nutrient uptake and reed growth. This, together with a growing understanding of biological and chemical nutrient uptake and retention abilities may provide a chance to protect the unique characteristics of wetlands such as South Milton Ley and ensure their long-term survival.

CHAPTER TEN

Conclusion and recommendations for further work

10.1 Conclusion

Comparison of reed growth over two years indicated that high TON, SRP and K can be linked to thin reeds with few seedheads and high density. In 1994 the reed variables height, diameter, number of internodes, biomass and number of seedheads were greater below the STW outlet than above. Values for TON, SRP and K were higher during this year than for 1995. During 1995 only seedhead production increased below the STW. The area of the Ley with the highest water levels contained the tallest reeds with greatest diameter and biomass in 1994 whereas the driest part produced plants with fewer seedheads and a higher density. In 1995 there was no significant difference in reed growth between wet and dry areas except for seedhead production which was greater in the wetter area. In laboratory experiments low N:K and high P:K ratios produced taller plants.

An increase in annual loading of TON and SRP and a decrease of K annual loading was recorded from 1992 to 1996. The efficiency of the RBTS during the study was low for all determinands. However concentrations of TON and SRP in effluent from the sewage treatment works remain well within the limits set by the consent to discharge.

Observations of the way in which the hydrology at South Milton Ley operates have confirmed the importance of irregular formation, development and breaching of the sand-bar which determines both the water volume held within the lake and hence its residence time and maintenance of the Ley in its present trophic state.

Results from this study together with information gained from literature suggest that the state of the Ley could be vulnerable. The reedbed appears to be a mature stand that is probably 'monoclonal' and does not contain a diverse genetic pool. Therefore if conditions for regression are present and regeneration by seedling growth is inhibited the decline of the wetland could be inevitable.

10.2 Recommendations for future work

Further study is needed in order to improve understanding of factors that affect reed growth together with investigations into how wetlands cope with increased nutrient loadings. In particular at South Milton Ley:

i) continued monitoring of water chemistry at Sites A to E to determine increased or decreased loadings to the system;

ii) continued monitoring of reed variables (height, biomass and density) within the reedbed and along the water margins to detect changes in growth and measurement of abundance of other plants (key competitors);

iii) continued hydrological measurements which could include testing for chloride ion across the Ley and also after the sand-bar is breached in order to determine how efficiently the Ley is flushed;

iv) determination of concentration of phytotoxins (acetic and butyric acid) which occur in soil water as a result of anaerobic decomposition within the reedbed;

v) investigation into the redox potential of soil in which reeds grow in order to determine O_2 availability for roots and rhizomes;

vi) Devise a management and monitoring plan together with the owners of the Ley (Devon Birdwatching and Preservation Society), English Nature and the Environment Agency.

APPENDIX ONE

Consents to discharge

08A/SOU

NATIONAL RIVERS AUTHORITY — Folio No. NRA-SW-3547

WATER RESOURCES ACT 1991 - CONSENT TO DISCHARGE — File No. 046/08A/0225

The National Rivers Authority, in pursuance of its powers under the above mentioned Act, HEREBY GIVES CONSENT to the discharge described hereunder subject to the terms and conditions set out below.

Name & Address of Applicant:	SOUTH WEST WATER SERVICES LTD PENINSULA HOUSE RYDON LANE EXETER EX2 7HR
Date of Application:	11 January 1991
Date of Consent:	14 February 1992
Description of Discharge:	
Type	Final Effluent
From (discharge location):	South Milton STW
To (outlet location):	South Milton Stream

Conditions

1. General

(a) Except with the agreement of the person making the discharge under this consent, no notice shall be served revoking the consent or modifying the conditions before 1 July 1994.

(b) For the purpose of applying the conditions, samples shall be taken at the outlet.

(c). This consent shall come into force on 1 July 1992.

2. As to Outlet

The outlet shall be sited at NGR SX 6860 4230 and shall be used only for the discharge of final effluent from the reed bed treatment system to South Milton Stream.

3. As to Discharge continued

(e) The discharge final effluent loading shall not have:

(i) a biochemical oxygen demand (BOD) in the presence of 0.5 milligrams per litre allyl thiourea (ATU) in five days at 20°C in excess of 50 milligrams per second.

(ii) in excess of 125 milligrams per second of suspended solids dried for one hour at 105 C.

(iii) in excess of 18 milligrams per second of ammoniacal nitrogen (as N).

(iv) a pH value greater than 9 or less than 6.

(v) in excess of 90 milligrams per second of nitrogen expressed as Total Oxidized Nitrogen.

(vi) in excess of 80 milligrams per second of phosphate expressed as total phosphate.

4. Facilities shall be provided for safe and convenient access to the whole site to enable Authority staff to take samples and carry out inspections.

5. Facilities for instantaneous effluent flow measurement shall be provided by the discharger to this Authority's sampling staff. This facility shall be maintained in good working order at all times to allow enforcement of the above loading conditions.

Manley House
Kestrel Way
Sowton Industrial Estate
Exeter

.... [signature]
Solicitor and Secretary
National Rivers Authority South West Region

ANNEX A

TABLE

(1) Series of samples taken in any year	(2) Maximum permitted number of samples which fail to conform to numerical limits
4 - 7	1
8 - 16	2
17 - 28	3
29 - 40	4
41 - 53	5
54 - 67	6
68 - 81	7
82 - 95	8
96 - 110	9
111 - 125	10

NATIONAL RIVERS AUTHORITY

WATER RESOURCES ACT 1991 - CONSENT TO DISCHARGE

Folio No. NRA-SW-3548

File No. 046/08A/0225

The National Rivers Authority, in pursuance of its powers under the above mentioned Act, HEREBY GIVES CONSENT to the discharge described hereunder subject to the terms and conditions set out below.

Name & Address of Applicant:	SOUTH WEST WATER SERVICES LTD PENINSULA HOUSE RYDON LANE EXETER EX2 7HR
Date of Application:	11 January 1991
Date of Consent:	14 February 1992

Description of Discharge:

Type	Storm Tank Effluent
From (discharge location):	South Milton STW
To (outlet location):	South Milton Stream

Conditions

1. General

(a) Except with the agreement of the person making the discharge under this consent, no notice shall be served revoking the consent or modifying the conditions before 1 July 1994.

(b) For the purpose of applying the conditions, samples shall be taken at the outlet.

(c) This consent shall come into force on 1 July 1992.

2. As to Outlet

The outlet shall be sited at NGR SX 6868 4232 and shall be used only for the discharge of storm tank effluent to South Milton Stream.

3. As to Discharge

(a) The rate of settled storm sewage discharging from the storm tank shall be limited to that in excess of the 12 litres per second passing forward to full treatment and when the storm tanks are full.

(b) Facilities for measuring flow at the flow separation weir shall be provided.

(c) The discharge shall:

(i) contain no visible signs of oil or grease.

(ii) contain no substances in concentrations injurious to fish.

(d) In any series of samples of the final effluent taken over any twelve month period as listed in column 1 of the table set out in the annex to this schedule, then, in respect of the following determinands, no more than the relevant number as permitted in column 2 of the table shall be in excess of 150 milligrams per litre of suspended solids (measured after drying at 105°C).

(e) A solids separation installation shall be provided to retain solids of greater than 6 millimetres in diameter.

4. Facilities shall be provided for safe and convenient access to the whole site to enable Authority staff to take samples and carry out inspections.

5. Alarmed telemetry shall be provided to warn of overflow operation. Records of overflow operation shall be maintained and provided to the Authority on request.

Manley House
Kestrel Way
Sowton Industrial Estate
Exeter

..........................J.K. Gray....
Solicitor and Secretary
National Rivers Authority South West Region

NATIONAL RIVERS AUTHORITY — Folio No. NRA-SW-6082

WATER RESOURCES ACT 1991 - CONSENT TO DISCHARGE — File No. 08A/SOU

The National Rivers Authority, in pursuance of its powers under the above mentioned Act, HEREBY GIVES CONSENT to the discharge described hereunder subject to the terms and conditions set out below.

Name & Address of Applicant:	SOUTH WEST WATER SERVICES LTD PENINSULA HOUSE RYDON LANE EXETER EX2 7HR
Date of Application:	2 April 1993
Description of Discharge:	
Type:	Treated Sewage Effluent
From:	South Milton STW
To:	South Milton Stream

Conditions

1. General

(a) Except with the agreement of the person making the discharge under this consent, no notice shall be served revoking the consent or modifying the conditions before 1 November 1995.

(b) For the purpose of applying the conditions identified in section 3 below, the discharger shall provide and maintain facilities to the Authority's satisfaction which will enable the Authority's representatives to take flow measurements of the treated sewage effluent which is discharged at the outlet.

The discharger shall identify the facility with a clearly visible sign distinguishing it from any other and provide a clearly visible notch, mark, or device indicating the level equivalent to the maximum instantaneous consented flow.

(c) For the purpose of applying the conditions identified in section 4 below, the discharger shall provide and maintain facilities to the Authority's satisfaction which will enable the Authority's representatives to take discrete samples of the treated sewage effluent which is discharged at the outlet. The discharger shall identify the facility with a clearly visible sign distinguishing it from any other.

(d) Facilities shall be provided for safe and convenient access to enable Authority's representatives at any time to take samples, carry out flow measurements and inspection to ensure that the conditions of this consent are complied with.

2. As to Outlet

The outlet shall be sited at NGR SX 6860 4230 and shall be so constructed that it is used for the discharge of treated sewage effluent derived only from this sewage treatment works.

3. As to Discharge

(a) The maximum instantaneous rate of discharge shall not exceed 12 litres per second.

(b) The volume discharged under dry weather flow conditions shall not exceed 320 cubic metres in any period of twenty four hours.

4. As to Discharge Composition

(a) The discharge shall:

(i) contain no visible signs of oil or grease.

(ii) contain no matter in a concentration which will cause the receiving waters to be poisonous or injurious to fish, the spawn of fish or the food of fish.

(b) Subject to condition 4(c) below, no sample of the fully treated effluent shall contain more than:

(i) 7 milligrams per litre of biochemical oxygen demand (nitrification suppressed) for five days at 20°C;

(ii) 14 milligrams per litre of suspended solids (measured after drying for one hour at 105°C);

(iii) 2 milligrams per litre of ammoniacal nitrogen expressed as nitrogen;

(iv) 11 milligrams per litre of phosphate expressed as Total phosphate.

(c) The limit for any of the determinands set out in condition 4(b) above may be exceeded where, in any series of samples of fully treated sewage effluent taken (whether before or after the grant of this consent) in the period of twelve months ending on the date of the discharge, as listed in Column (1) of the table at Annex A to this Consent, no more than the relevant number of samples, as listed in Column (2) of the said table, exceeds the applicable limit for that determinand at the time when a sample is taken, that is in respect of samples taken after the grant of this consent, the limit set out in condition 4(b), and in respect of samples taken before the grant of this consent, the corresponding provision of the consent then in force.

(d) Notwithstanding conditions 4(b) and 4(c) above, no single sample of the fully treated sewage effluent discharged shall have:

(i) in excess of 14 milligrams per litre of biochemical oxygen demand (nitrification suppressed) for five days at 20°C;

(ii) in excess of 35 milligrams per litre of suspended solids (measured after drying for one hour at 105°C);

(iii) in excess of 4 milligrams per litre of ammoniacal nitrogen expressed as nitrogen;

(iv) in excess of 22 milligrams per litre of phosphate expressed as Total phosphate;

(v) a pH value less than 6 or greater than 9.

....

Technical Manager
National Rivers Authority
South Western Region

14/10/97

Date of Consent

Manley House
Kestrel Way
Sowton Industrial Estate
Exeter
Devon EX2 7LQ

ANNEX A

TABLE FOR ASSESSMENT OF CONSENT COMPLIANCE

COLUMN (1) Series of samples taken in any year	COLUMN (2) Maximum permitted number of samples which fail to conform to numerical limits
4 - 7	1
8 - 16	2
17 - 28	3
29 - 40	4
41 - 53	5
54 - 67	6
68 - 81	7
82 - 95	8
96 - 110	9
111 - 125	10

APPENDIX TWO

Assessment of the performance of *Phragmites Australis* Cav. Trin. Ex Steudal in absorbing increased nutrient loadings from non-point and small point sources

Paula Powell[1], S D Lane[2], P E O'Sullivan[1] and P J Worsfold[1].

1. Department of Environmental Sciences, University of Plymouth, Plymouth, PL4 8AA, UK.

2. Department of Biological Sciences, University of Plymouth, Plymouth, PL4 8AA, UK.

P. australis is the most important reedswamp species in the British Isles. Many of its habitats receive increased nutrient loadings mainly from disposal of waste (especially sewage) and/or agricultural runoff. This research is concerned with the effects of nutrient enrichment on *P. australis* and its potential use as an indicator of wetland habitat status.

Fieldwork has been undertaken at South Milton Ley, a freshwater wetland, Site of Special Scientific Interest in Devon, England. The Ley receives effluent from a sewage treatment works which has recently been enlarged to provide tertiary treatment via an artificial reedbed.

In order to assess the performance of *P. australis,* the hydrology and nutrient availability of the natural reedbed have been monitored together with measurement of physical characteristics of reeds. The shortest and those with the smallest diameter, have been found upstream of the STW.

Concentrations of N, P and K have been determined in surface, soil and effluent waters. In 1992 annual orthophosphate and total oxidised nitrogen loads were 3.65 and 69.4 g m^2 a^{-1} and in 1995, 16.70 and 63.53 g m^2 a^{-1}. Although the nutrient input is increasing the Ley does not exhibit signs of eutrophication. This may not imply that the present loading is acceptable; it may be that no eutrophication has yet been observed because physical conditions have so far prevented it. Further studies of nutrient loadings and controlled laboratory experiments to determine effects of various concentrations and ratios of NPK on *Phragmites australis* will be undertaken during 1996.

Assessment of the performance of *Phragmites Australis* Cav. Trin. Ex Steudal in absorbing increased nutrient loadings from non-point and small point sources

Paula Powell[1], E Baron[2], S D Lane[3], P E O'Sullivan[1] and P J Worsfold[1]

1. Department of Environmental Sciences, University of Plymouth, Plymouth, PL4 8AA, UK.
2. Institut Universitaire de Technologie de Lannion, Dept. Mesures Physiques, IUT Lannion, France.
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Introduction

In the United Kingdom there were once extensive areas of wetland, namely the Somerset Levels, the Fens in eastern England, Romney Marsh and many other coastal marshes and inland wetlands. Only a third of the original Fenland now survives and half of UK water meadows have been lost since the 1930s (**Rackham 1986**).

Phragmites australis Cav Trin. ex Steudel (Common Reed), is one of the most widely distributed grasses of temperate wetlands, (**Boar 1987**). In the British Isles *P. australis* is the most important reedswamp species. Many of its habitats receive increased nutrient loadings mainly from disposal of waste (especially sewage) and/or agricultural runoff. This research is concerned with the effects of nutrient enrichment on *P. australis* and its potential use as an indicator of wetland habitat status.

Site Description

Fieldwork has been undertaken at South Milton Ley in South Devon, England, (**Figure one**). The Ley is a predominantly freshwater wetland and is the second largest reedbed in the county. The site is owned by a conservation body, the Devon Birdwatching and Preservation Society and was designated a Site of Special Scientific Interest (the principal UK category of site protection for conservation) in 1976. It contains one of the best examples of freshwater reed-bed in Devon and is particularly important for its breeding bird community and for the variety of birds using the site on passage (SSSI citation 1984).

South Milton Ley has received effluent from a sewage treatment works (STW) since 1960. The works dealt with domestic wastewater from a peak population of 340. Two years ago the STW was enlarged to serve an increased population (maximum summer population of 1,500 by the year 2000) and an artificial reedbed was incorporated into the works in order to provide tertiary treatment.

The Ley measures 1.5 km in length and is on average 100m wide, with a total area of 0.17km^2. The vegetation of the lower part of the Ley consists chiefly of the Common Reed *Phragmites australis*. The hydrology of the Ley consists of a combination of systems which operate independently but which interact to create effects which are both seasonal and stochastic. At its western end it is periodically separated from the sea by the formation of a sand-bar. The lake which forms behind this consists of brackish water, being subject to occasional tidal influence, but upstream the Ley contains only fresh water. The main freshwater input to the upper Ley is South Milton Stream. The stream receives storm runoff from road drains before entering the Ley; in addition to which both the stream and Ley are recipients of runoff from the surrounding agricultural land.

At the coastal end of the Ley, is a west facing storm beach which is subject to sand-bar formation. This can occur at any time of year following a period of gale force winds from the west or south west. Once the sand-bar has formed, a lake develops behind it as incoming fresh water flowing through the reed-bed accumulates. An additional input to the Ley is sea water which sometimes washes over the bar when high tide coincides with strong winds. The length of time during which the Ley acts as a lake or a river and its periodic flushing when the sand-bar breaks, are of prime importance to the nutrient budget of the system. This has retarded ecological succession and maintained the conditions in which the reedbed has flourished.

Fieldwork

A field sampling programme has been established in order to determine the performance of *P. australis* over one growth year. The factors which regulate production such as climate, hydrology and nutrient availability are being monitored together with measurement of characteristics of reed. It was decided to collect samples at the time of maximum standing crop (equivalent to stage 10.5 in cereals). This will have provided a sufficiently accurate measure of above-ground production as losses of biomass during the growing season are small for emergent macrophytes **(Graneli 1985)**. In order to determine concentrations of N, P and K in surface and soil waters, sampling sites have been set up along the Ley and at the artificial reedbed in the sewage treatment works.

RESULTS

The results of analysis of physical characteristics of reeds indicate that there are differences in height, diameter, internodes, density and biomass. The shortest reeds and those with the smallest diameter, are found upstream of the STW. Reed height increases downstream of the STW as do stem diameter, density (no. reeds per m^{-2}) and biomass (g m^{-2}).The variation of mean shoot height throughout the Ley was 12.6cm to 170.8cm. This was lower than shoot measurements observed in other studies, for example, **Boar (1987)**, and **Kvet (1971)**. Mean diameter of shoots varies from 2mm-8mm, a similar range to that found by **Boar (1987)**. Biomass values of 272-3494 (g m^{-2}) are also comparable. Shoot density (no. shoots $m^{-2)}$ ranges from 12-155 compared with 40-700 in Broadland, Eastern England **Boar (1987)**.

Table one indicates the nutrient loading to South Milton Ley. The annual input of orthophosphate during 1994 was 16.70 g m^{-2} a^{-1} . The loading rate for Slapton Ley (a similar site in Devon, UK) was 6.2 g m^{-2} a^{-1} **(O'Sullivan *et al.* 1989)**. The maximum residence time at South Milton (11 days) is just over half that of Slapton Ley (18 days). Therefore in comparison, the loading rate for South Milton Ley is higher than that of Slapton Ley and its lower residence time may not be able to compensate for this extra nutrient burden.

Table 1. Mean Daily Load of Orthophosphate and Total Oxidised Nitrogen (Kg d^{-1})

PO_4 kg d^{-1}	Point	Diffuse	TON kg d^{-1}	Point	Diffuse
1992	0.36	1.81	1992	3.15	26.69
1993	0.79	0.36	1993	3.37	77.76
1994	2.67	5.4	1994	4.19	25.4

DISCUSSION

At its present loading rate there is a great deal of evidence of eutrophication in the Lower Ley at Slapton (**O'Sullivan and Wilson 1993**). South Milton Ley does not show signs of eutrophication at present, however this cannot be taken to imply that the present loading is acceptable; it may be that no eutrophication has yet been observed because physical conditions have so far prevented it. Breaching of the sand-bar at times of high levels of nutrients could cause these to be rapidly flushed from the system. Further study of this complex system is needed. Monitoring of nutrient loadings in ground-water and the effects of NPK and water depth on the growth of *Phragmites australis* will be the future programme of research for 1995.

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APPENDIX THREE

A) Standard errors of the means for reed variables from South Milton Ley 1994

	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6
Transect 6	4.2	8.1			3.4	2.5
Transect 5	7.0	12.3			9.3	10.6
Transect 4	5.6	8.5	17.1	12.0	11.3	9.3
Transect 3	4.9	5.8	9.3	4.3	9.9	4.5
Transect 2	0.0	0.0	2.7	5.4	5.7	6.9
Transect 1	7.8	15.4	10.0	17.1	14.1	10.4

Table A1: Standard error for height

	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6
Transect 6	0.3	0.3			0.3	0.3
Transect 5	0.3	0.3			0.3	0.4
Transect 4	0.3	0.6	0.3	0.5	0.5	0.5
Transect 3	0.3	0.5	0.3	0.3	0.3	0.3
Transect 2	0.0	0.0	0.3	0.4	0.6	0.3
Transect 1	0.3	0.4	0.4	0.3	0.4	0.4

Table A2: Standard error for diameter

	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6
Transect 6	0.3	0.4			0.4	0.4
Transect 5	0.3	0.3			0.3	0.4
Transect 4	0.4	0.6	0.4	0.5	0.6	0.4
Transect 3	0.6	0.3	0.5	0.3	0.5	0.3
Transect 2	0.0	0.0	0.3	0.4	0.6	0.7
Transect 1	0.4	0.6	0.4	1.1	0.3	0.4

Table A3: Standard error for internodes

B) Standard errors of the means for reed variables from South Milton Ley 1995

	Plot 1	Plot 2	Plot 3	Plot 5	Plot 6
Transect 6	3.3	2.4	3.7	2.1	5.1
Transect 4	4.9	8.4	9.8	7.1	6.0
Transect 3	13.0	17.1	10.8	10.8	4.9
Transect 2	0.0	8.4	5.8	4.6	6.6
Transect 1	0.0	14.3	6.2	4.6	5.4

Table B1: Standard error for height

	Plot 1	Plot 2	Plot 3	Plot 5	Plot 6
Transect 6	0.8	0.6	0.6	1.1	1.5
Transect 4	0.3	0.8	0.9	1.1	1.1
Transect 3	1.2	1.0	1.0	1.3	2.0
Transect 2	0.0	0.9	1.7	0.8	1.3
Transect 1	0.0	2.5	0.3	1.1	1.5

Table B2: Standard error for diameter

	Plot 1	Plot 2	Plot 3	Plot 5	Plot 6
Transect 6	0.3	0.3	0.3	0.3	0.4
Transect 4	0.3	0.4	0.3	0.4	0.3
Transect 3	0.6	0.9	0.5	0.4	0.5
Transect 2	0.0	0.4	0.3	0.3	0.3
Transect 1	0.0	0.7	0.4	0.3	0.4

Table B3: Standard error for internodes

C) Standard errors of the means for reed variables from Laboratory experiment

	Tank 1	Tank 2	Tank 3	Tank 4
June	7.4	10.0	6.7	12.3
August	7.5	11.3	10.2	9.7
October	7.7	5.9	7.6	10.7
November	7.5	4.4	8.6	9.1

Table C1: standard errors for height

	Tank 1	Tank 2	Tank 3	Tank 4
June	0.7	0.8	0.7	1.0
August	0.4	0.9	0.5	0.6
October	0.4	0.6	0.3	0.3
November	0.3	0.3	0.3	0.3

Table C2: standard errors for diameter

	Tank 1	Tank 2	Tank 3	Tank 4
June	0.4	0.4	0.3	0.6
August	0.3	0.6	0.5	0.3
October	0.7	0.4	0.9	0.9
November	0.7	0.6	0.8	0.6

Table C3: standard errors for internodes

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